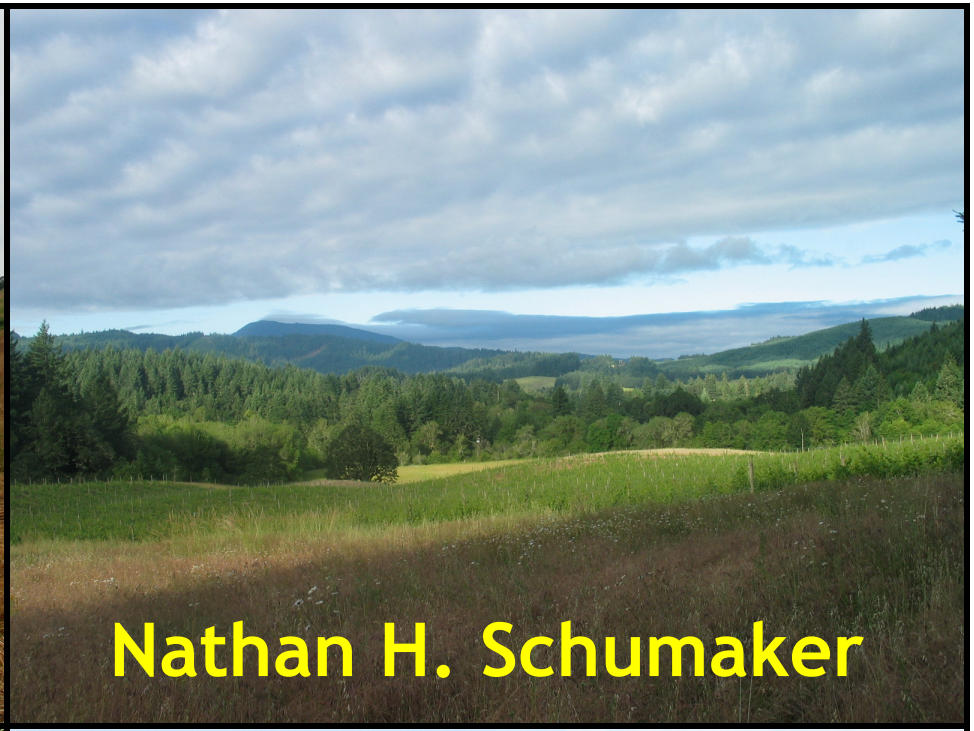
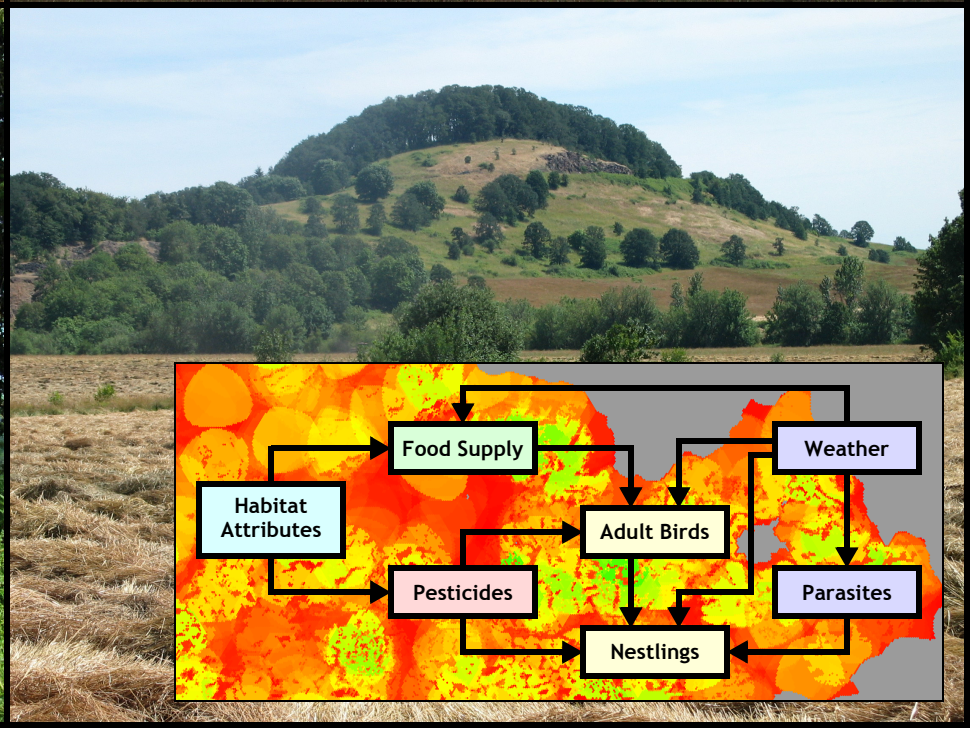
Integrating Landscapes Structure with Wildlife Life History and Stress



Nathan H. Schumaker



Introduction

Today's seminar will explore the influence of landscape structure from two different angles:

- **By examining some contrasts between simple and more complex wildlife models**
- **By exploring links between habitat quality, landscape structure, and population dynamics**

HexSim History

Has existed in some form for about 15 years now...

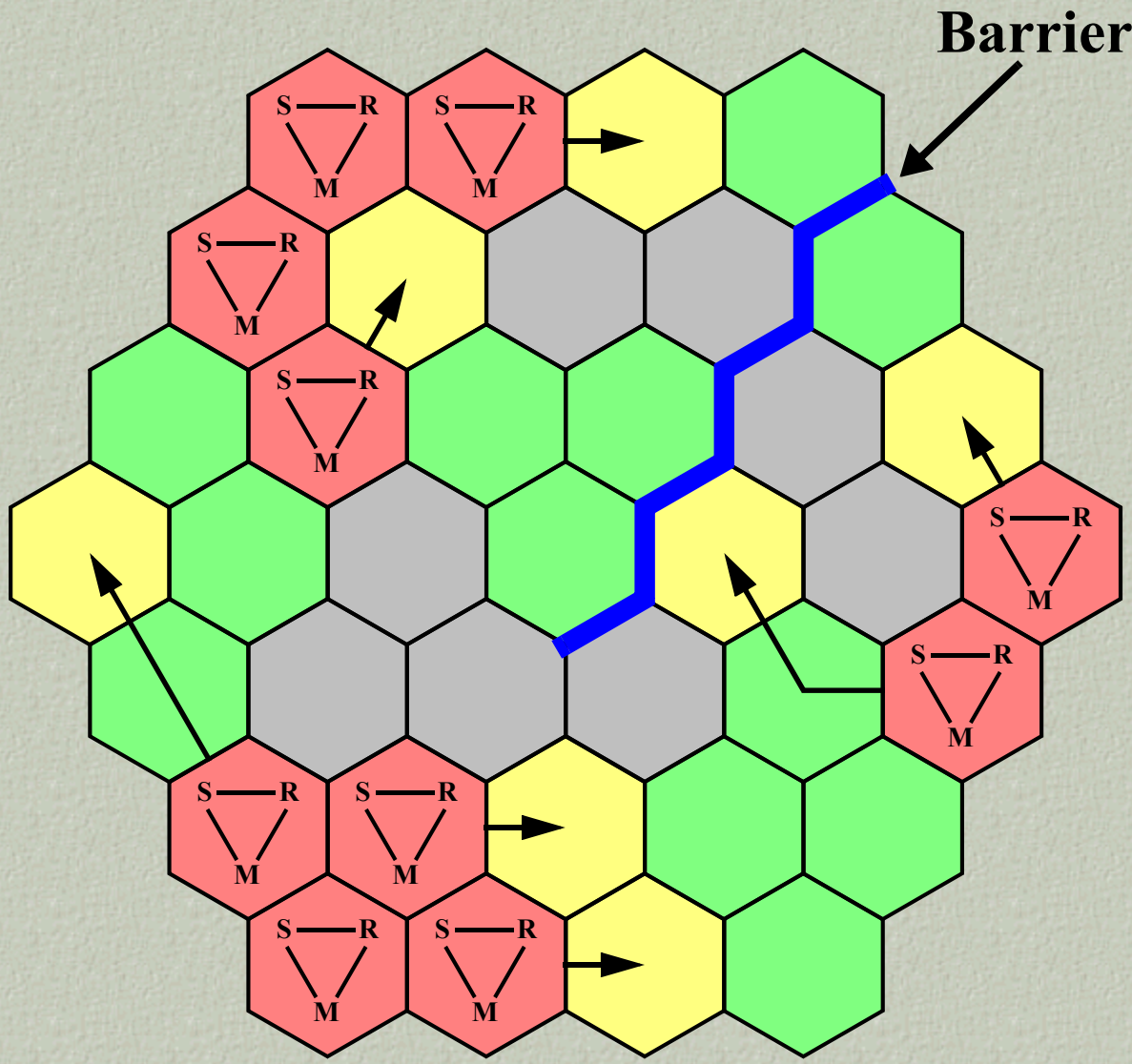
- **Circa 1992**
  Original version began as a grad student project
- **1995 - 2000**
  Focused mostly on landscape structure
- **2001 - Present**
  Expanded to address multiple species / stressors

What Is It?

A SEPM that attempts to balance realism, generality, and parsimony

- **Life cycle composed of user-defined events**
- **Most events have spatial drivers**
- **Individual-based, with traits that can change**
- **Simulations can range from simple to complex**

HexSim Basics



Non-Habitat

Available Habitat

Occupied Habitat

Colonized Habitat

Movement Path

S = Survival

R = Reproduction

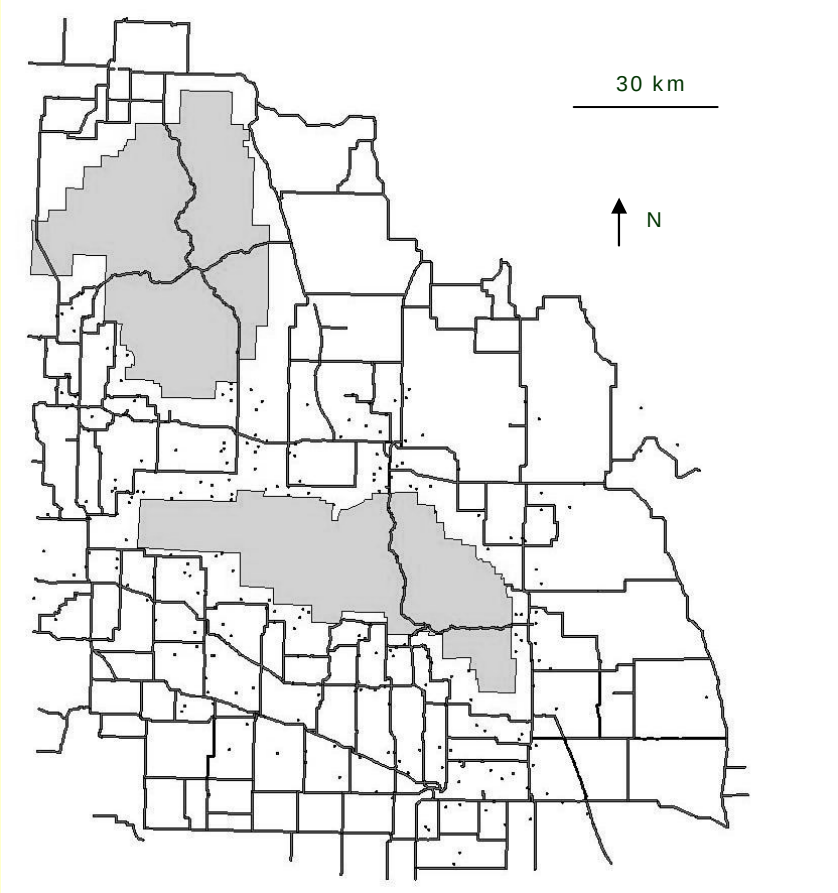
M = Movement

Landscape resistance to dispersal: The Great Plains agricultural matrix

Riding Mountain National Park

Study area

- Duck Mountain Provincial Park and Forest (5,000 km^2)
- Riding Mountain National Park (RMNP 3,000 km^2)



No

- Dispersal barriers
- Natural ecological transitions

Forest →farm fields
Influence dispersal?

Study organism: Gray wolves (*Canis lupus*)

For which

- Habitat fragmentation
- Human-caused mortality
- Disease

may threaten long-term survival in the Riding Mountain region

Disease

Late 1970's:

- Bovine Tuberculosis (n = 2)
- Distempervirus (n = 3)

After 1992:

- Sarcoptic Mange

Wildlife disease concern: wolves surrounded by dogs & coyotes

Management concern: Disease

- Inbreeding, parvovirus, distemper
  can reduce pup survival
- Inbreeding
  can reduce allelic diversity

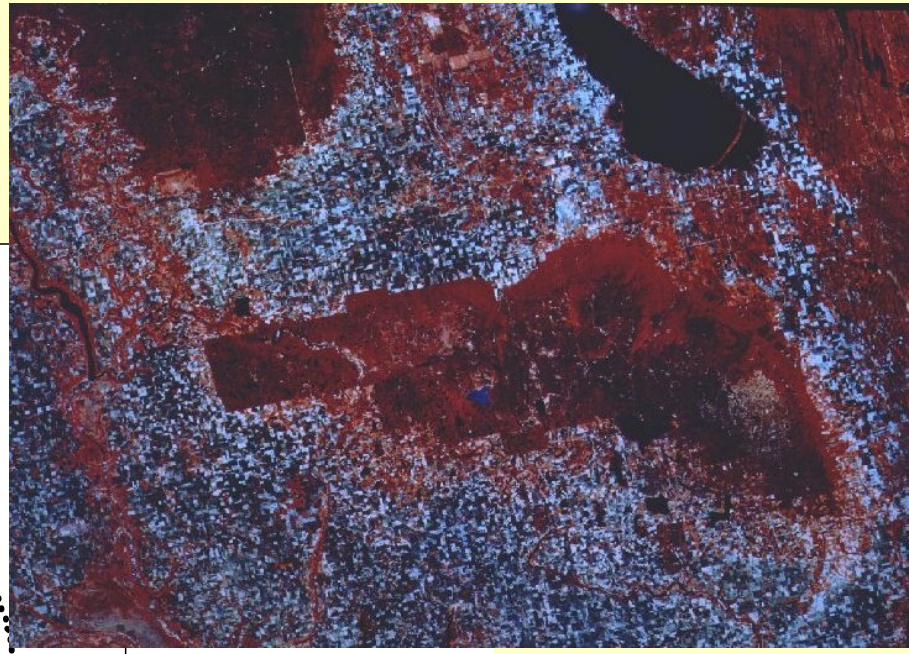
- Possible interactions between disease, inbreeding, & reduced survival of young

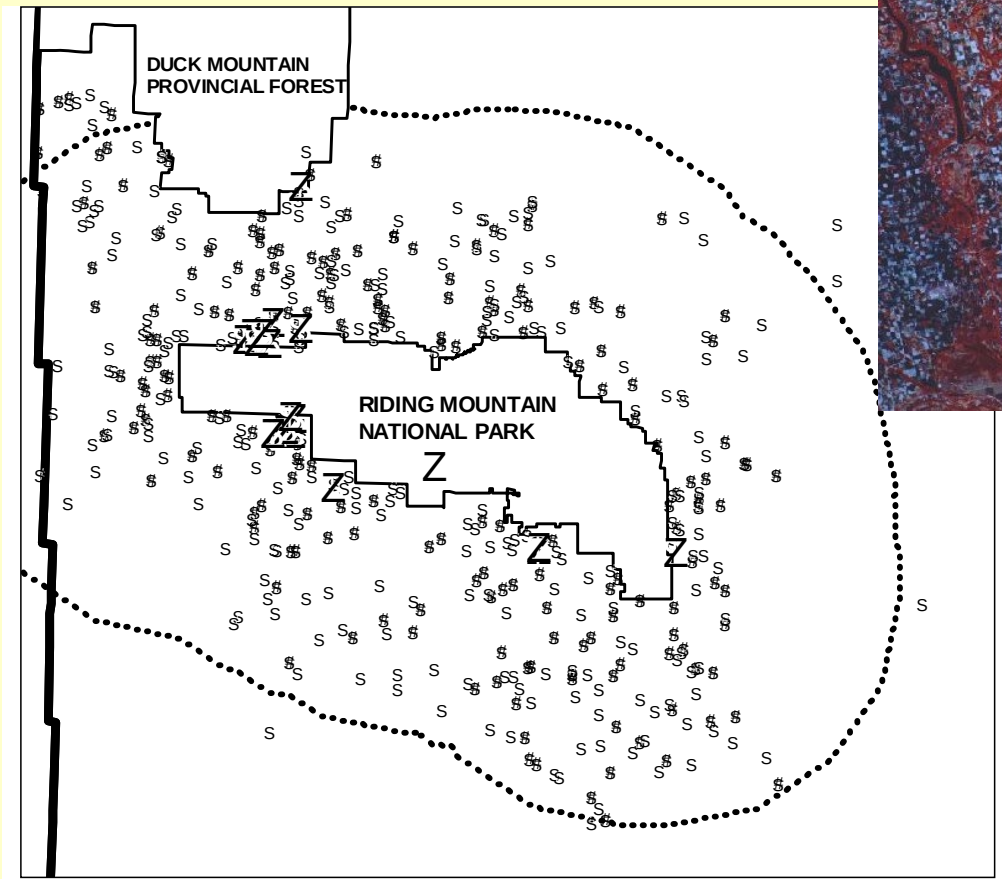
Human-caused mortality

- 1987 – 96: 58 known
- 2001: Wolf hunting closed around RMNP; may shoot in defence of property
- Recent: shooting, poison, coyote trapping

Management concern: Connectivity

Dispersal:
corridors of positive attitudes?





○ dislike seeing wolves

● like seeing wolves

Δ TB positive cases

Stronen et al. 2007

Dispersal modeling with HexSim

- Examine influence of disease mortality on emigration: Pup survival reduced from 0.46 to 0.2 every 3rd, 5th and 10th years

- Examine disperser success in human-modified landscapes: Effects of mortality from roads & negative human attitudes (25%, 50%, 75%)

Dispersal modeling with HexSim

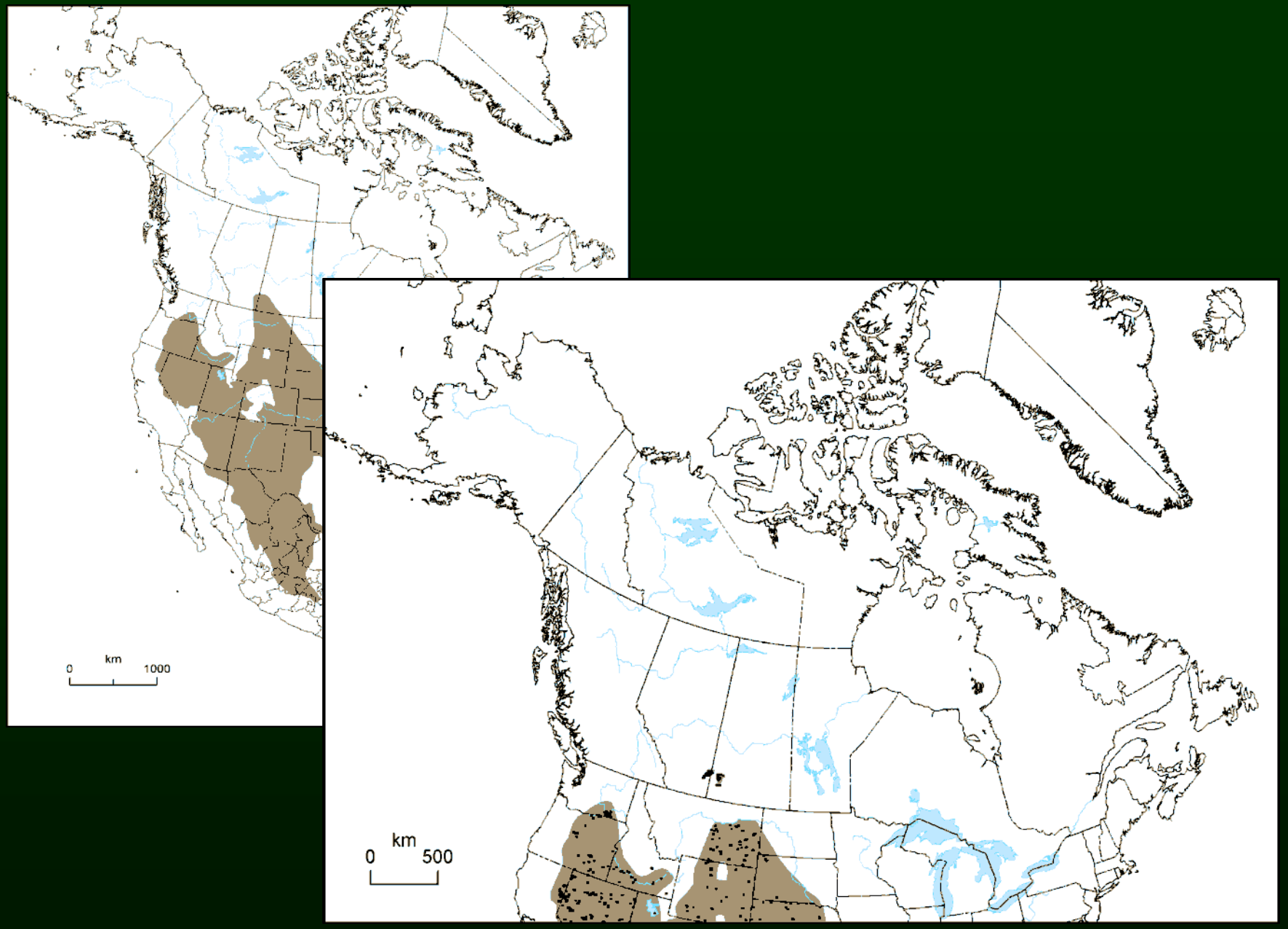
- Roads may reduce dispersal even when not barriers (no fence, low volume)
- Animals may travel extensively, but limited net dispersal (consistent with field data)

Identifying Critical Habitat for the Ord's Kangaroo Rat in Alberta

Darren Bender DavidGummer

Julie Heinrichs Randy Dzenkiw

UNIVERSITY OF CALGARY


km
0
1000
km
0
500

Status in Canada

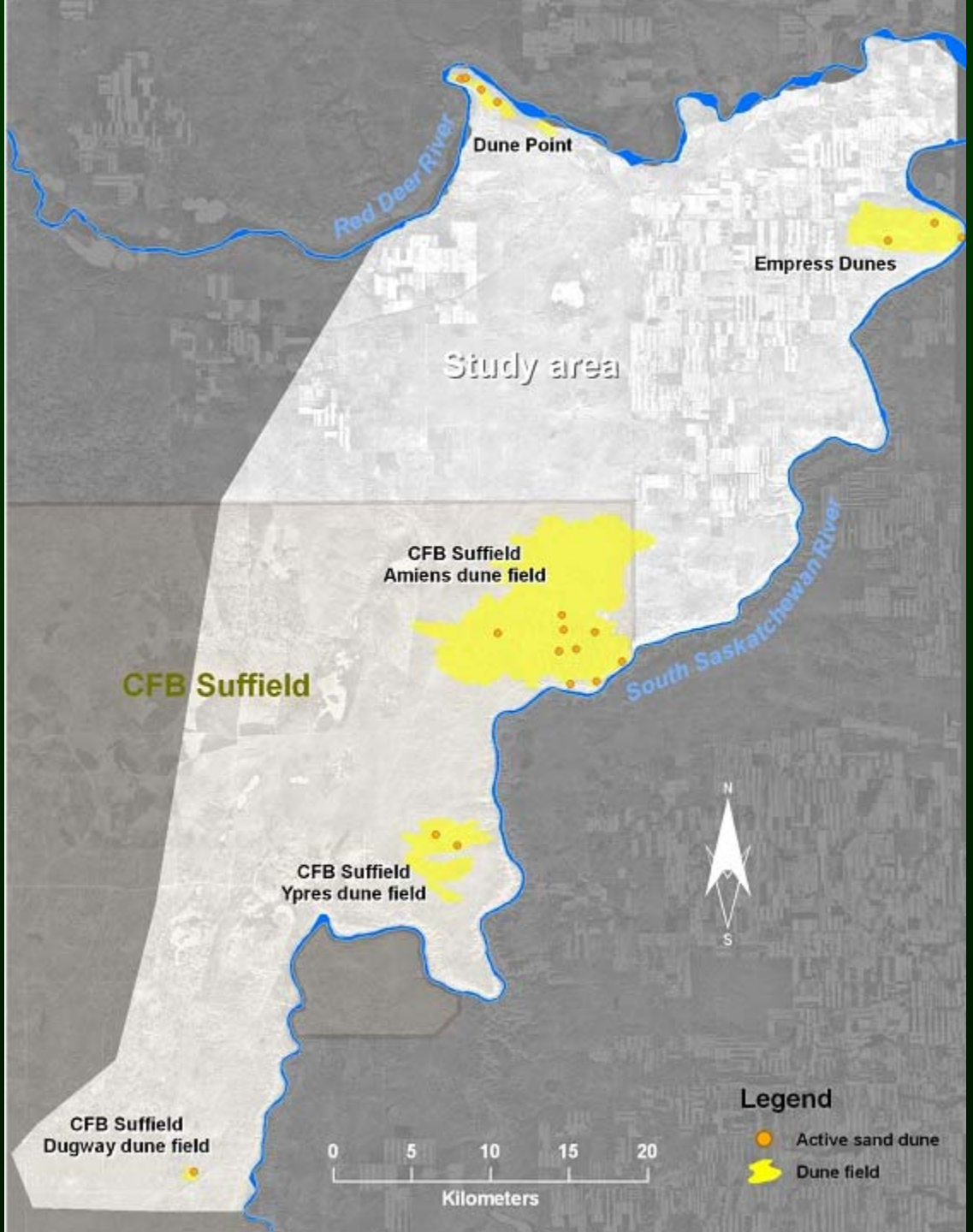
- Listed as Endangered in Alberta in 2002
- Up-listed to Endangered by COSEWIC in 2006

- Reasons for designation:
  - area of occupancy is < 53 km^2 (~ 2 km^2 natural)
  - < 1000 individuals range-wide in some years
  - extreme seasonal population fluctuations (up to 95% mortality annually)
  - requires highly specialized habitats that are disappearing (could be within 10 years in AB)
    - Geographically isolated with small EOO

Uniquely Canadian Characteristics

- Morphology – very large body size
- Physiology – only population in genus that is capable of hibernating
- Reproductive behaviour – reduced gestation and higher frequency of mating

Habitat Identification

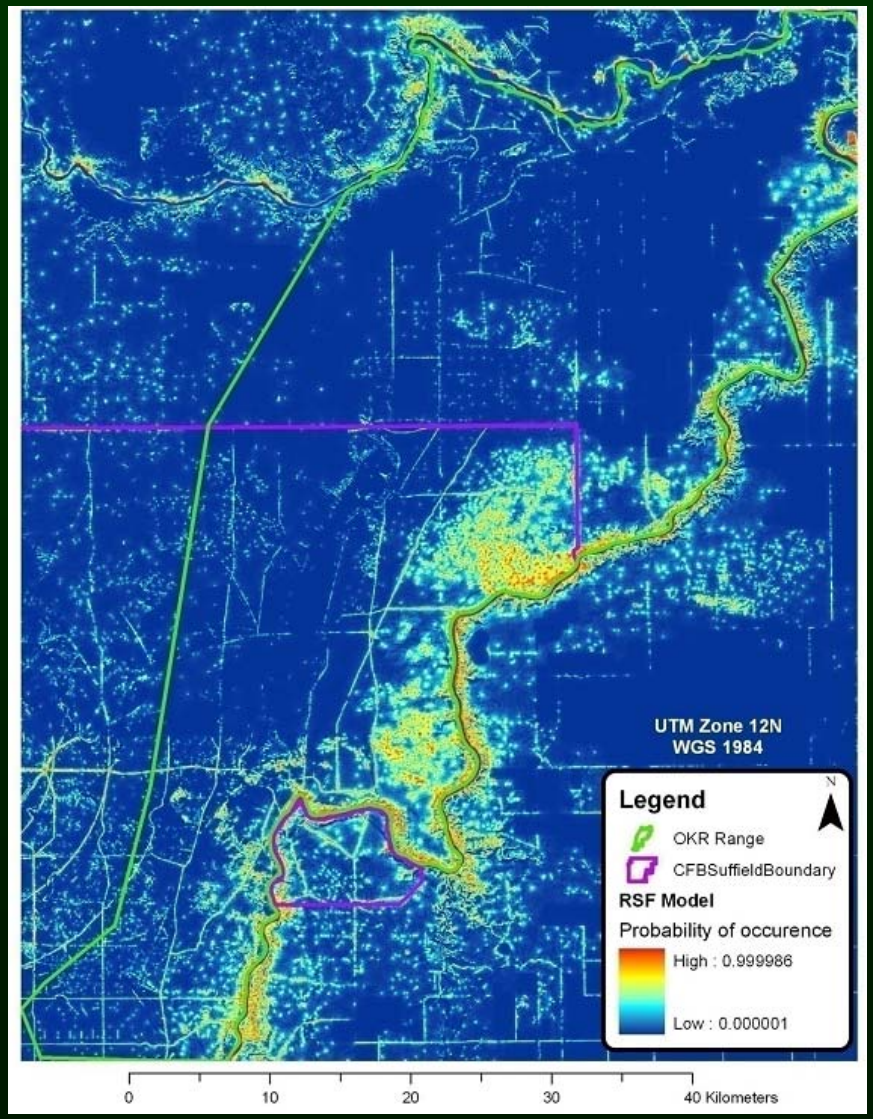

Red Deer River
Dune Point
Empress Dunes
Study area
CFB Suffield
Amiens dune field
CFB Suffield
South Saskatchewan River
CFB Suffield
Ypres dune field
N
S
CFB Suffield
Dugway dune field
0
5
10
15
20
Kilometers
Legend
Active sand dune
Dune field

Kangaroo rats also use secondary habitats

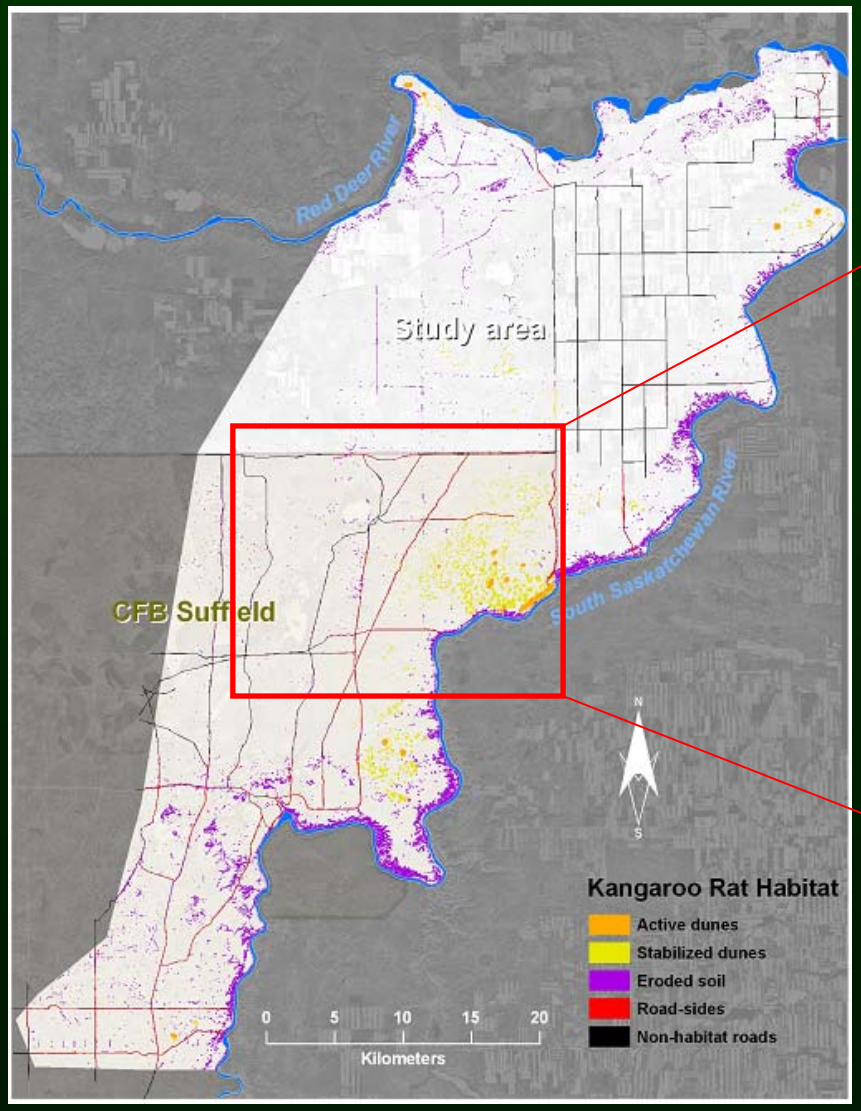
- secondary habitats:
  - semi-stable dunes
  - other naturally eroding sandy soils (e.g., crests of river valley)
  - sandy roads, trails, fireguards, or other anthropogenic linear features
  - margins of some agricultural fields

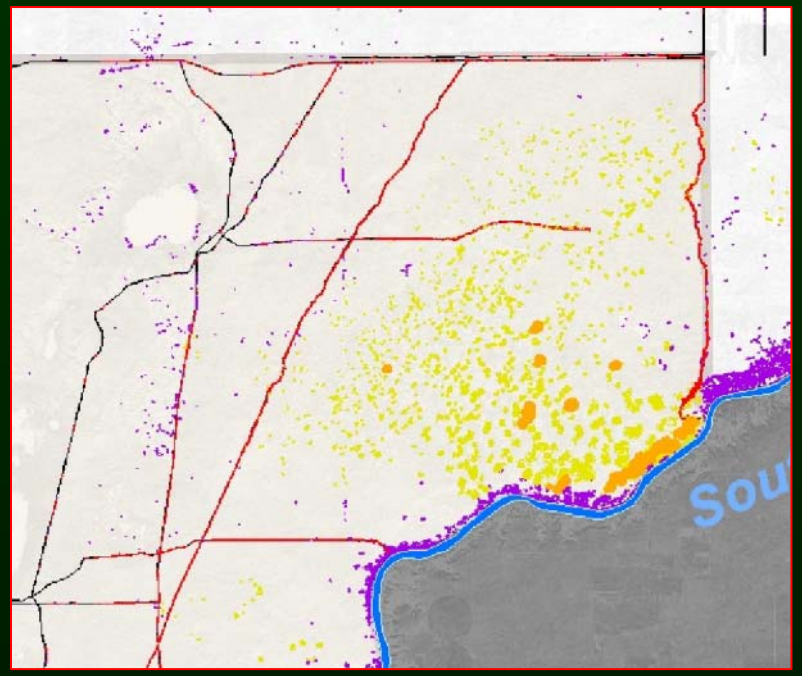
Example: Ord's kangaroo rat in AB

- Used RSF approach to generate predicted occurrence (habitat) map
- Validated multiple ways:
  - expert scrutiny
  - receiver operating curve (ROC) plots
  - binned rank-correlation plots
  - k-fold cross validation*
- Delineate habitat boundaries at threshold of P(occ) = 87%



Overlay Quality and Barriers





Population Model

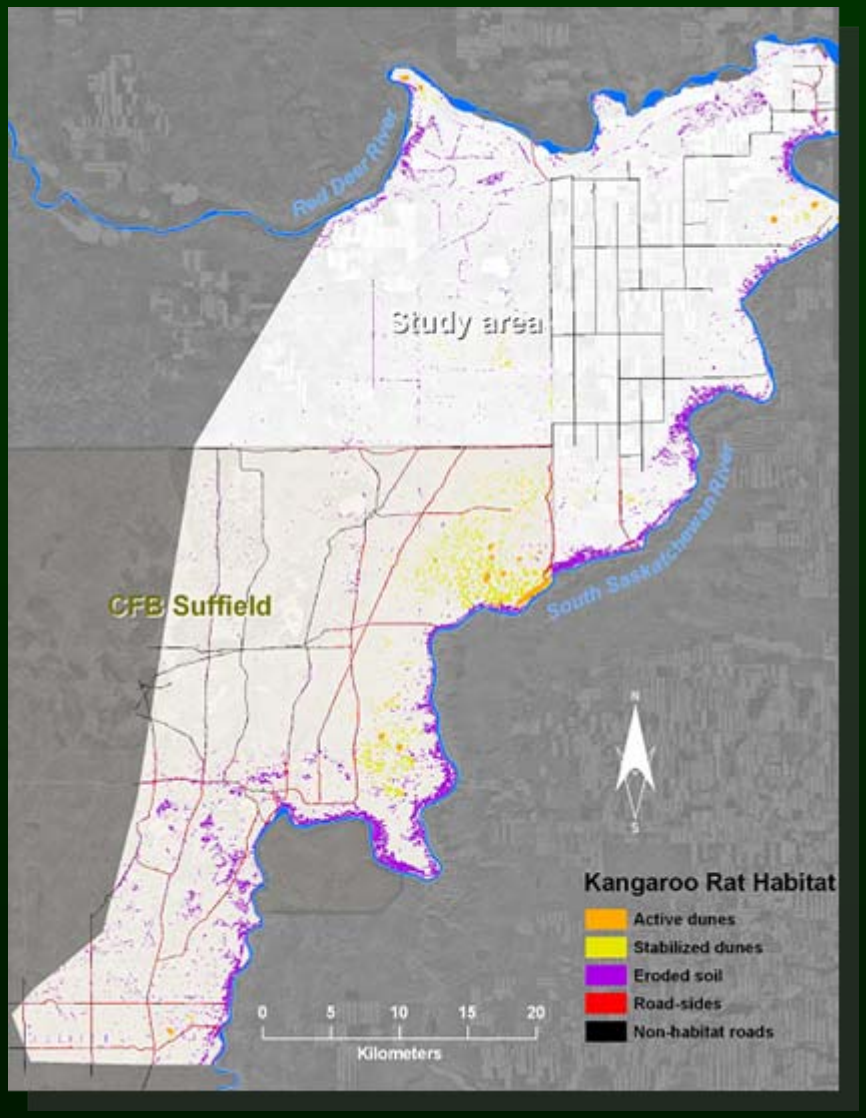
- Spatially Explicit Population Model Software: HexSim (PATCH)
  - Free, available from the US EPA
  - Used for many high profile species, e.g., Northern Spotted Owl and Gray Wolf
  - Individual-based, spatially-explicit model
    - Movements and reproductive success of individuals are tracked through time
    - Explicit interaction with the landscape
      - Simulates realistic dispersal, habitat selection, etc.

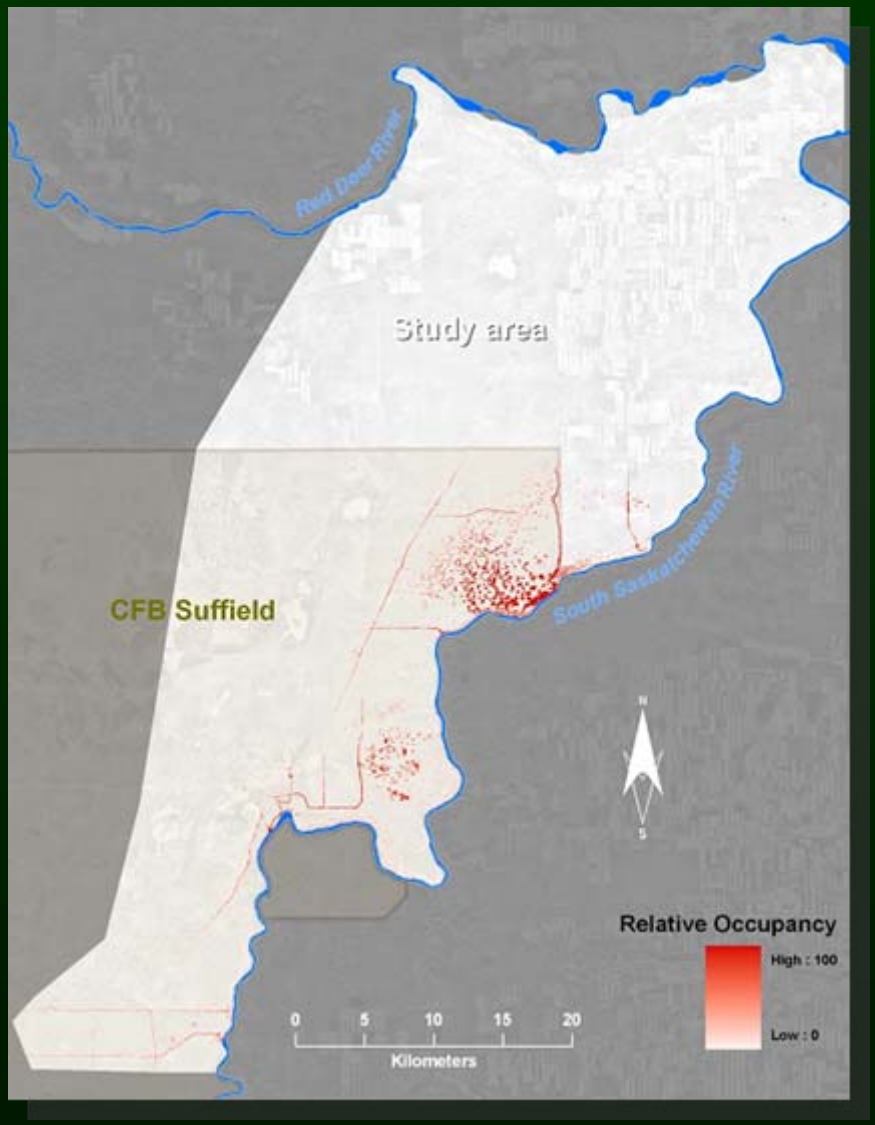
Population Model

Population Viability Analysis of Habitat Scenarios

- Biological parameters from population studies
- Simulated 450 years; 1000 repetitions
  - Allowed 50 years for initial conditions to stabilize
- Target criterion (survival and recovery):
  - Scenarios with a P.E. <10% in 100 years represented scenarios that may provide long-term persistence and recovery

Results


Red Deer River
Study area
CFB Suffield
South Saskatchewan River
N
S
Kangaroo Rat Habitat
Active dunes
Stabilized dunes
Eroded soil
Road-sides
Non-habitat roads
0 5 10 15 20
Kilometers

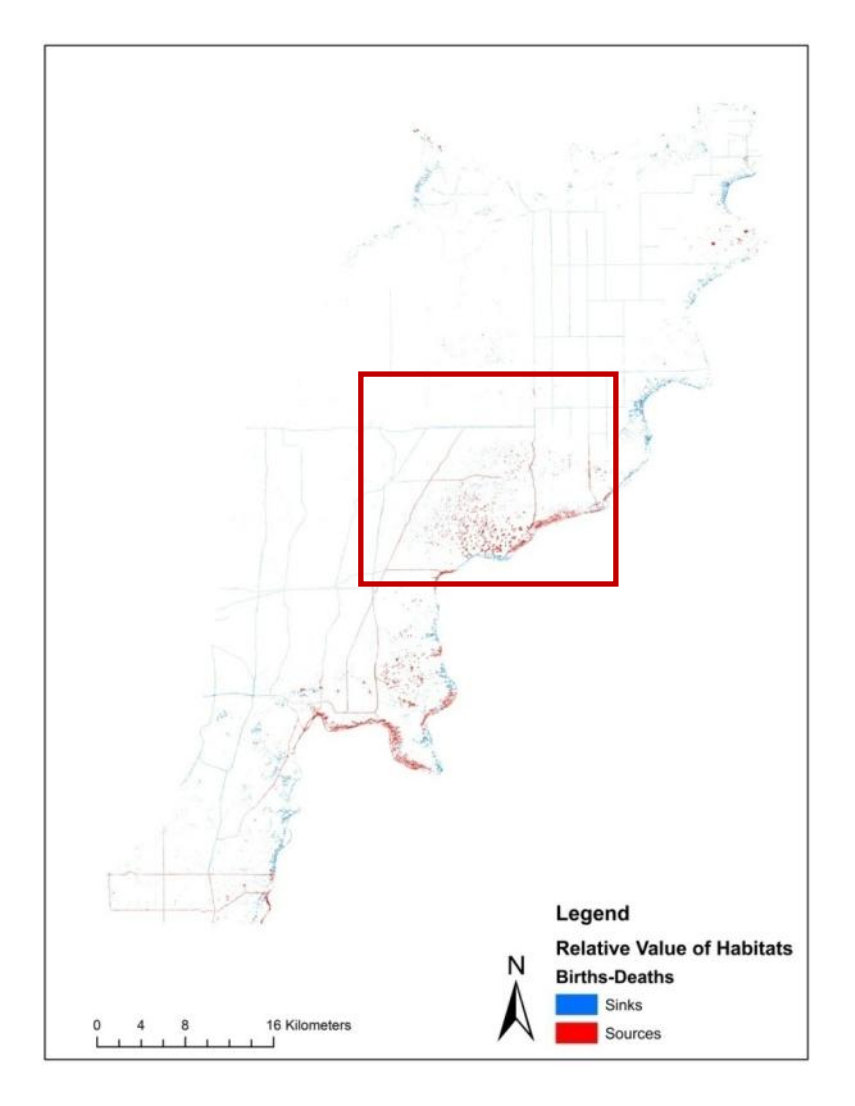

Red Deer River
Study area
CFB Suffield
South Saskatchewan River
N
S
Relative Occupancy
High : 100
Low : 0
0 5 10 15 20
Kilometers

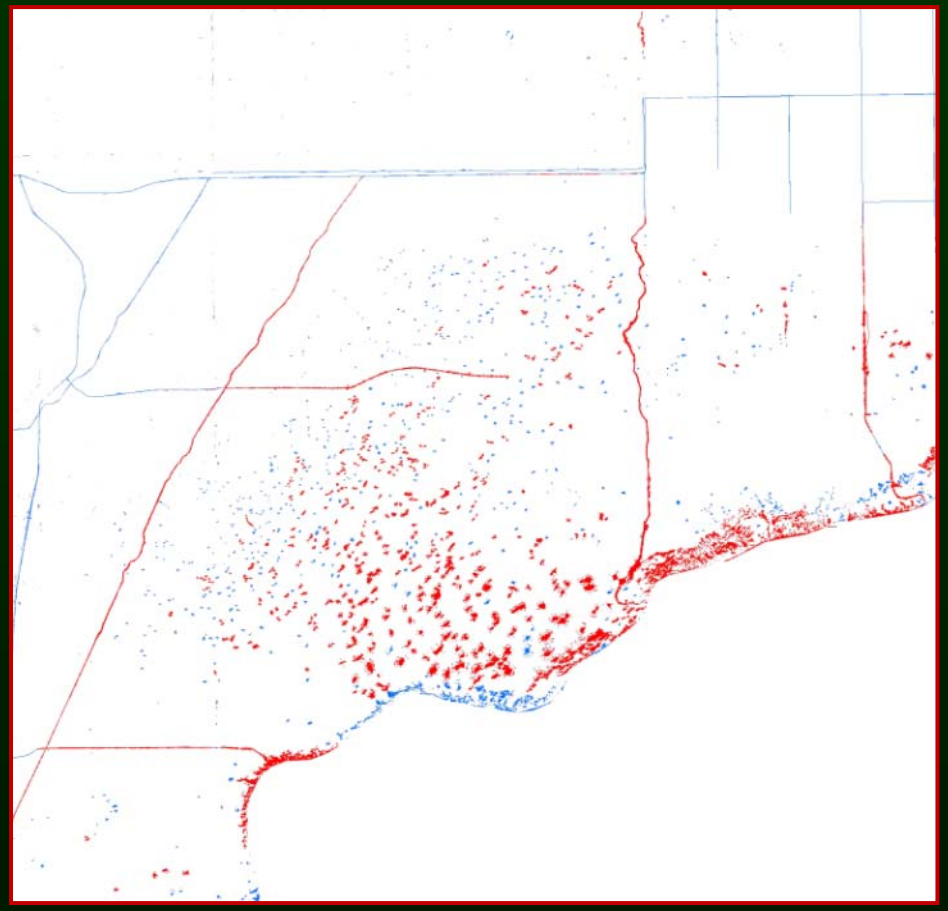
Results

Population Model: Baseline Scenario

- Included all habitat from thresholded RSF
- Probability of extinction
  - At year 100: 23%
  - P.E. >10% over 100 years
  - Insufficient habitat for kangaroo rat persistence or recovery (target not met)
- Distinguishes the habitat that actually contributes to population persistence

Source/sink identification





What is the risk of not incorporating quality?

- The RSF occurrence model does not incorporate quality information
- How does the model change if we do not differentiate a difference in quality between primary (natural) and secondary habitats?

Habitat Quality Scenario	Probability of Extinction (Over 100 yrs)
No Habitat Quality Differences	1%
Habitat Quality Differentiation	23%

Habitat change scenarios

Scenario	P.E.	Habitat Area (ha)	Change in P.E. Per 10 ha Habitat Removed
Baseline – all habitat	23%	2792.76	+ 0.08 %

Habitat change scenarios

Scenario	P.E.	Habitat Area (ha)	Change in P.E. Per 10 ha Habitat Removed
Baseline – all habitat	23%	2792.76	+ 0.08 %
Removed all active sand dunes	35%	68.29	+ 5.125 %

Habitat change scenarios

Scenario	P.E.	Habitat Area (ha)	Change in P.E. Per 10 ha Habitat Removed
Baseline – all habitat	23%	2792.76	+ 0.08 %
Removed all active sand dunes	35%	68.29	+ 5.125 %
Removed all road habitats	37%	424.14	+ 0.87 %

Habitat change scenarios

Scenario	P.E.	Habitat Area (ha)	Change in P.E. Per 10 ha Habitat Removed
Baseline – all habitat	23%	2792.76	+ 0.08 %
Removed all active sand dunes	35%	68.29	+ 5.125 %
Removed all road habitats	37%	424.14	+ 0.87 %
Removed all road sink habitat	22%	68.37	- 3.20 %

Habitat restoration scenario

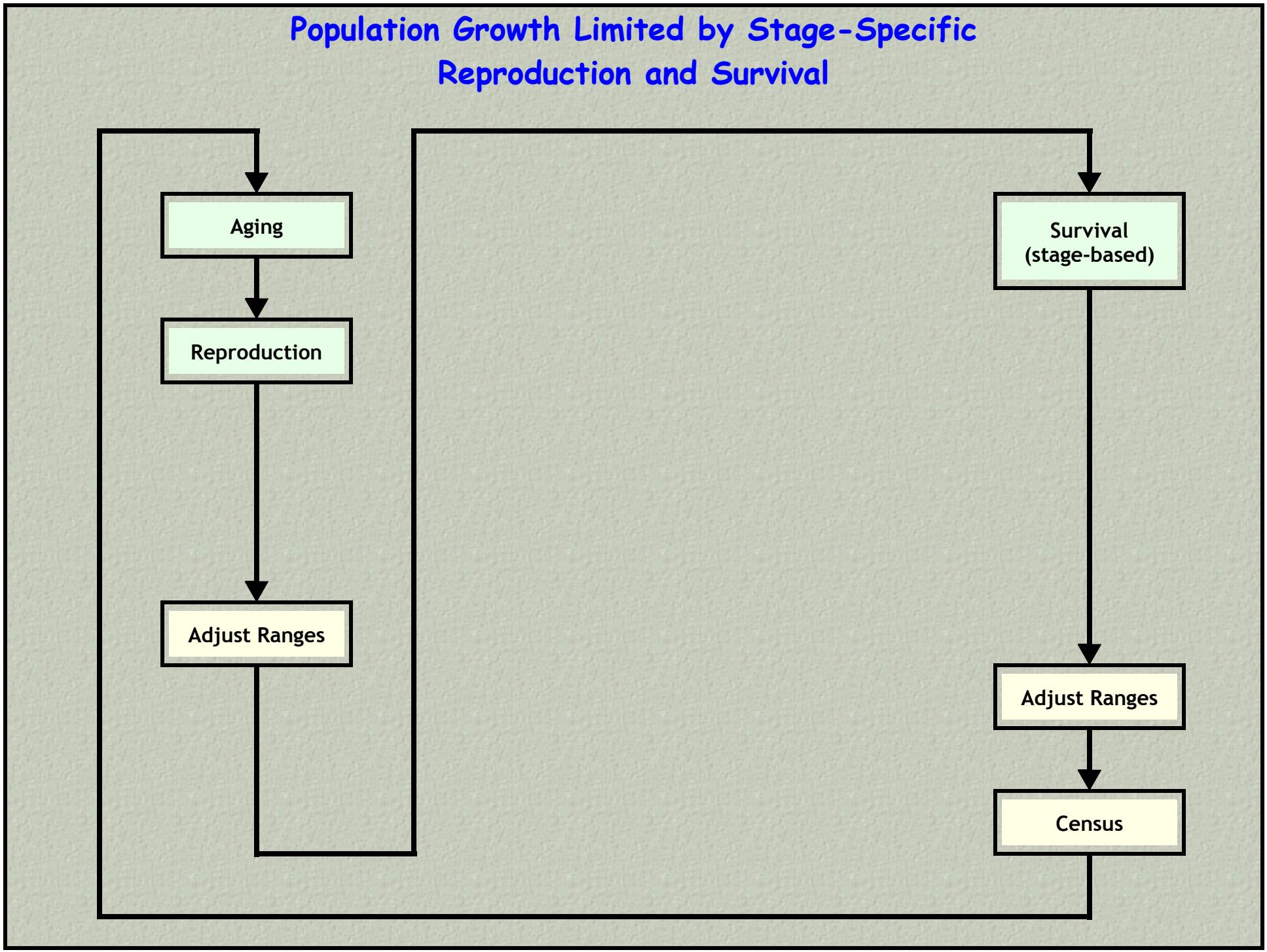
- Effect of adding primary habitat?
  - adding 12 new sites decreases P.E. by 5 – 8%
  - about 0.5% per new dune restored

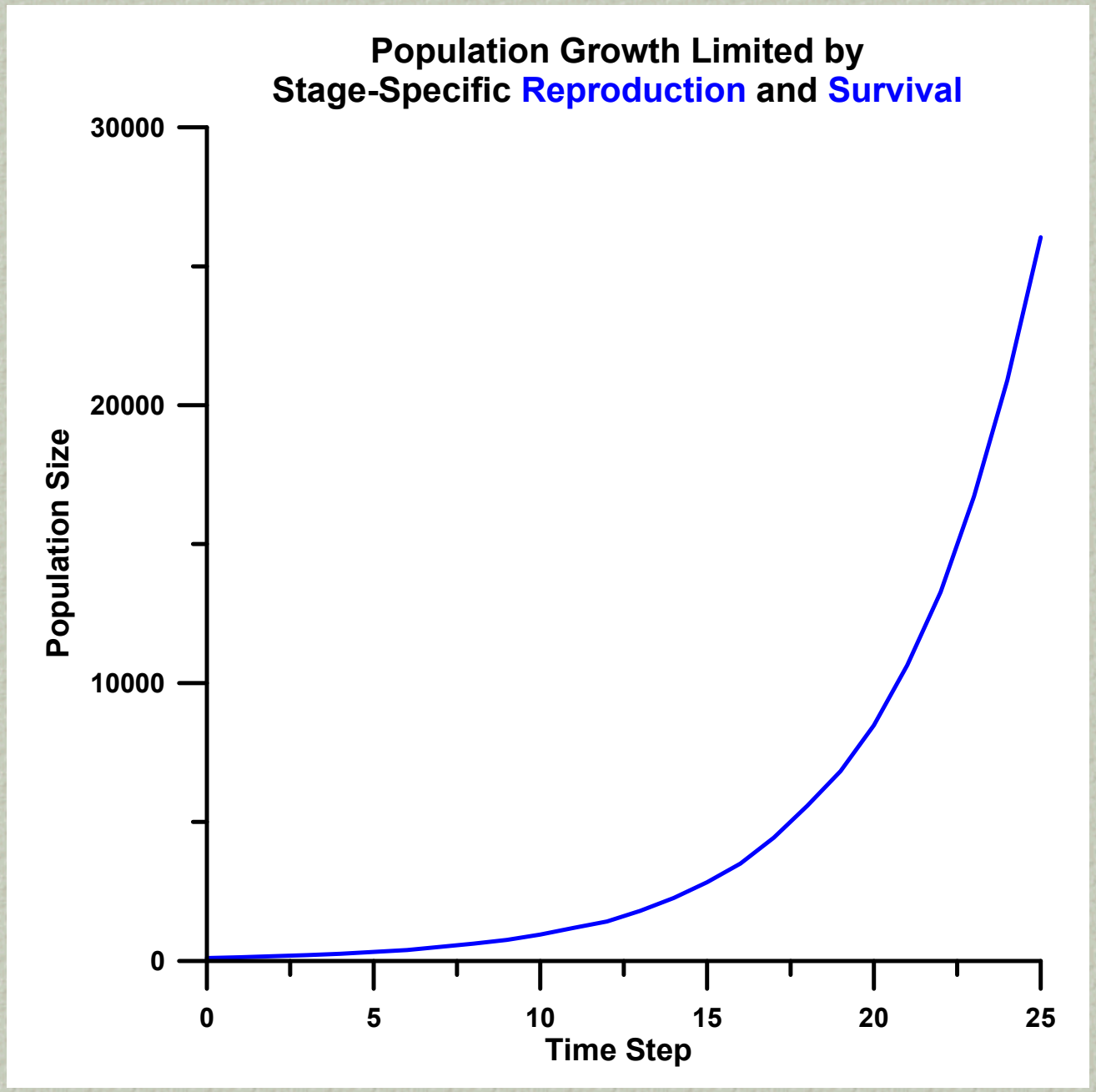
Start Simple

- Three stage classes correspond to ages 0, 1, 2
- Survival and reproduction vary with stage class
- Individuals try to aggregate into groups <= 10
- Space is not limiting

The result is exponential growth, with the growth rate tempered by the vital rates.

Population Growth Limited by Stage-Specific Reproduction and Survival



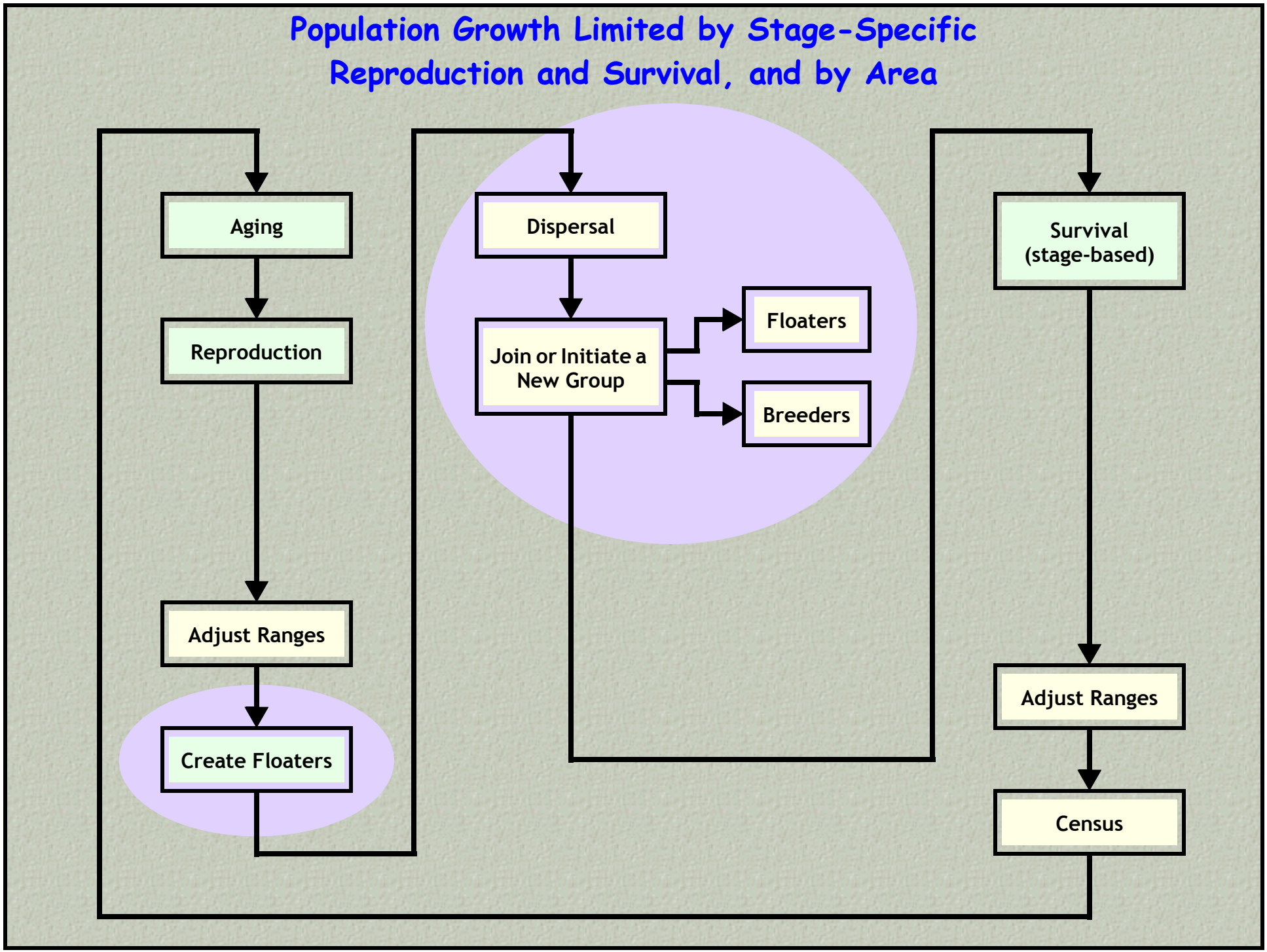

Population Growth Limited by
Stage-Specific Reproduction and Survival
30000
20000
10000
0
Population Size
0
5
10
15
20
25
Time Step

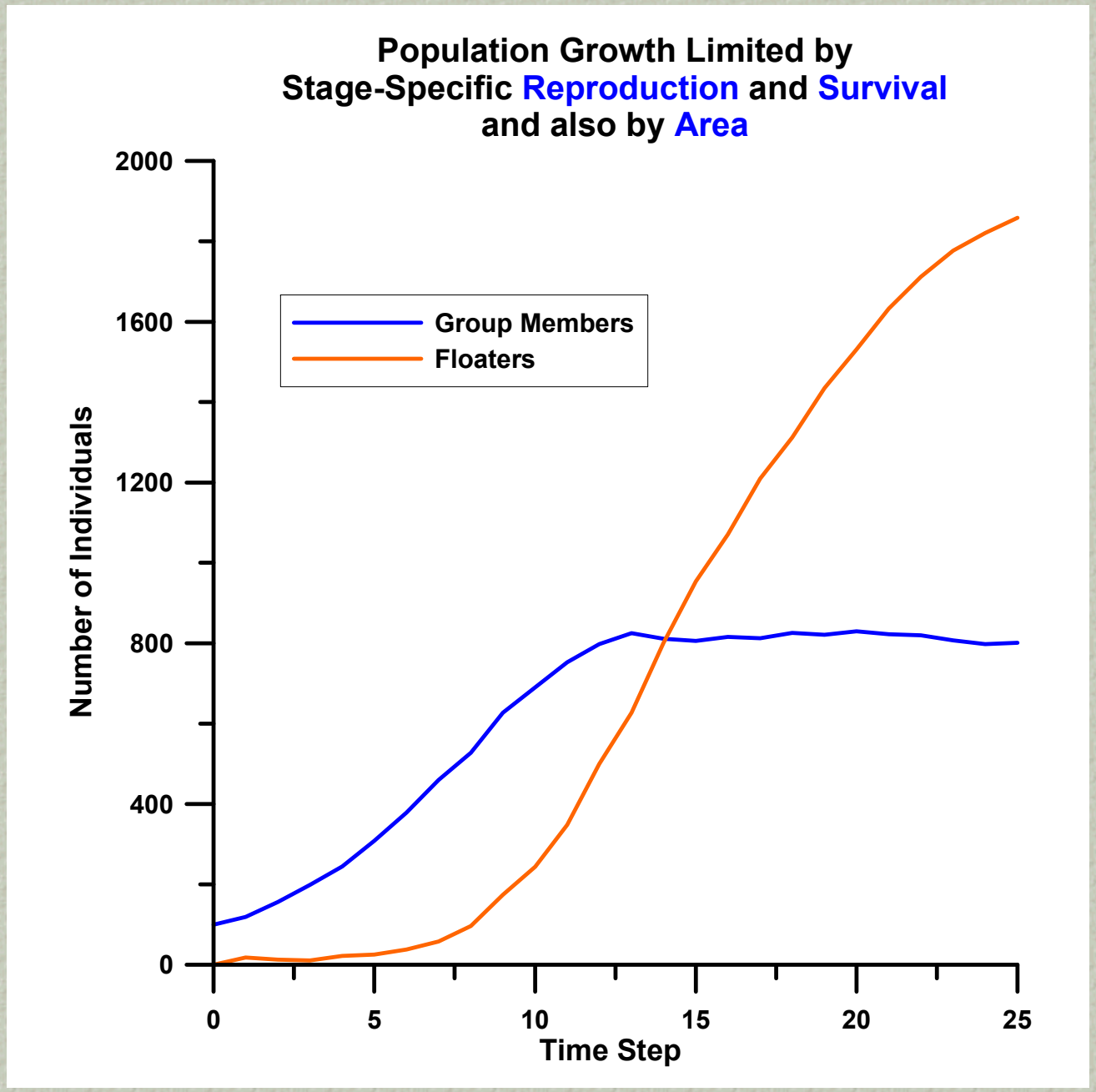
Add A Little Realism

- Three stage classes correspond to ages 0, 1, 2
- Survival and reproduction vary with stage class
- Individuals try to aggregate into groups <= 10
- Space is finite, but only affects reproduction

Two classes of individuals emerge -- Breeders & Floaters
Breeders need home ranges, which are in limited supply
Breeder populations reach a carrying capacity
Floater populations grow indefinitely

Population Growth Limited by Stage-Specific Reproduction and Survival, and by Area



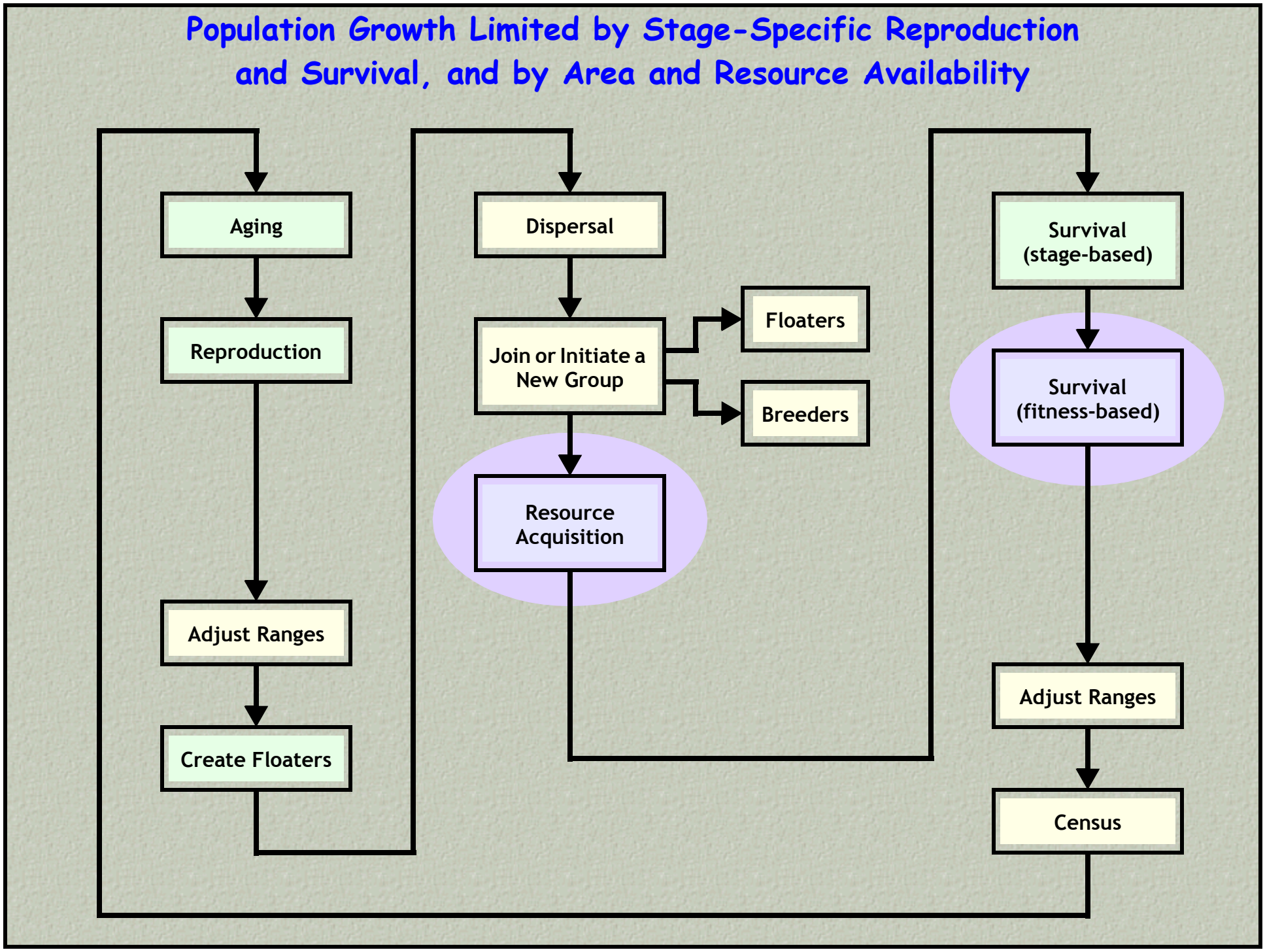

Population Growth Limited by
Stage-Specific Reproduction and Survival
and also by Area
Group Members
Floaters
Number of Individuals
2000
1600
1200
800
400
0
0
5
10
15
20
25
Time Step

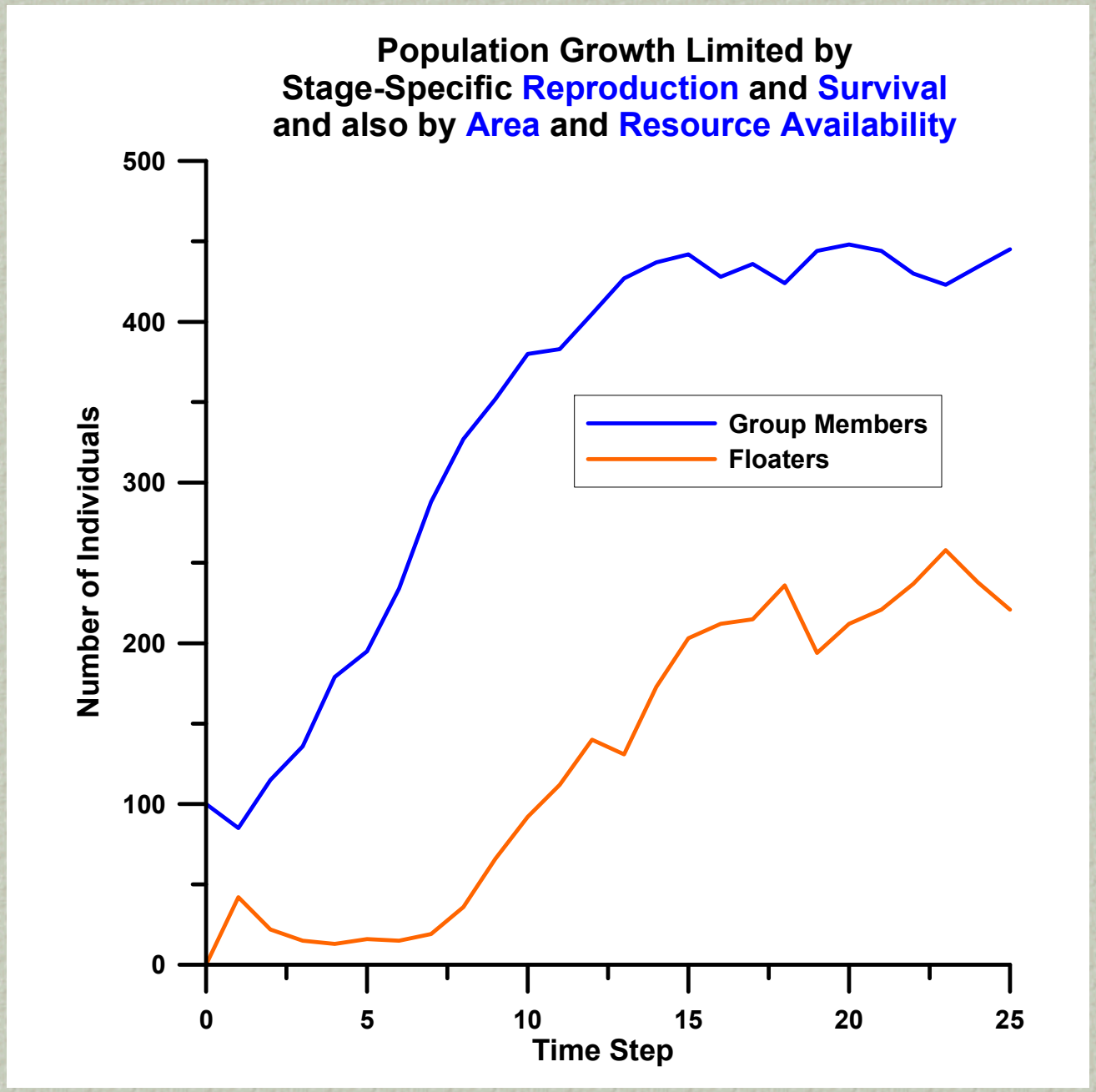
Add Additional Realism

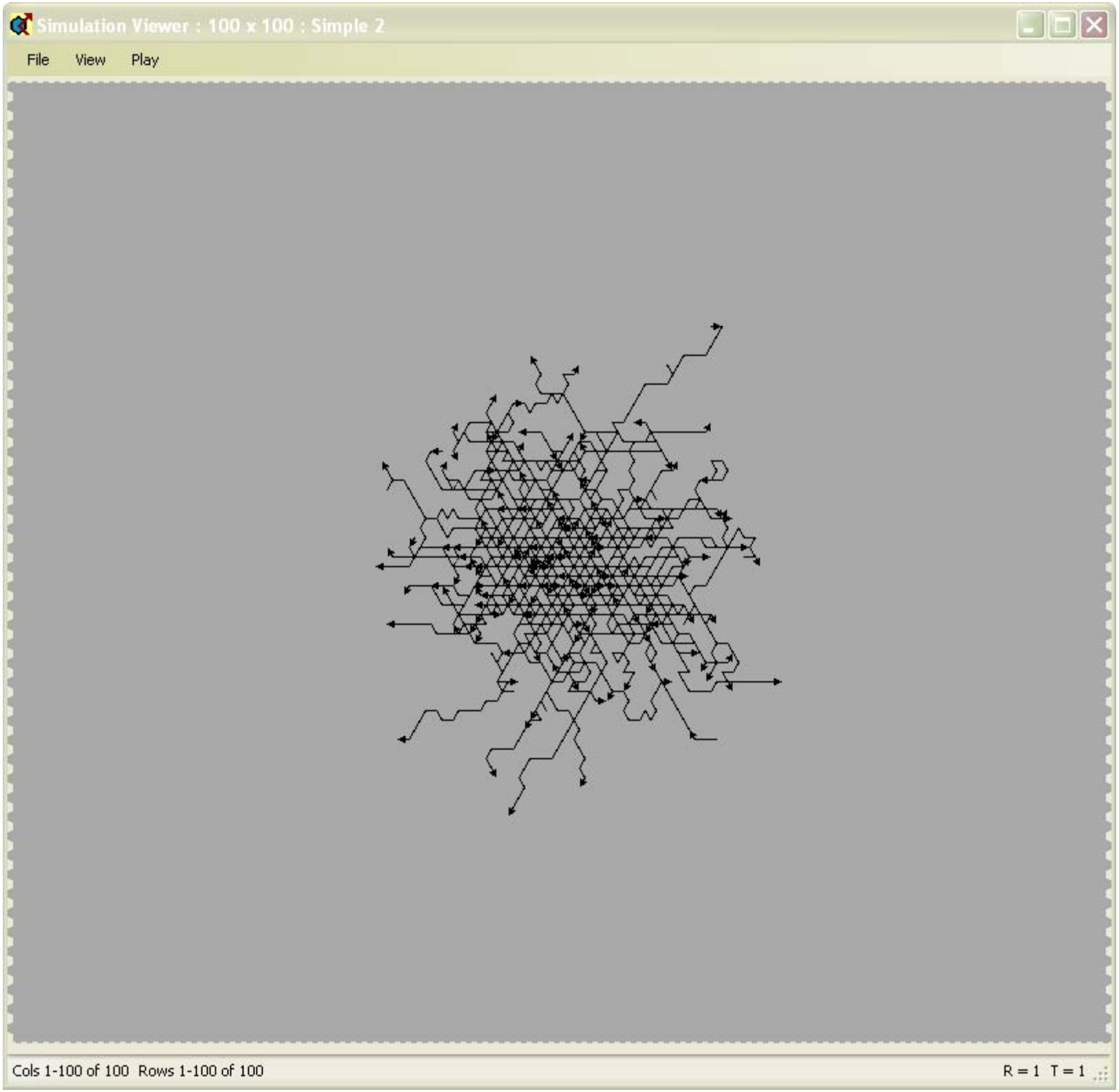
- Three stage classes correspond to ages 0, 1, 2
- Survival and reproduction vary with stage class
- Individuals try to aggregate into groups <= 10
- Space is finite, and affects survival & reproduction
- Resource acquisition is smoothed across 3 time steps
- Acquired fitness levels are low, medium, and high

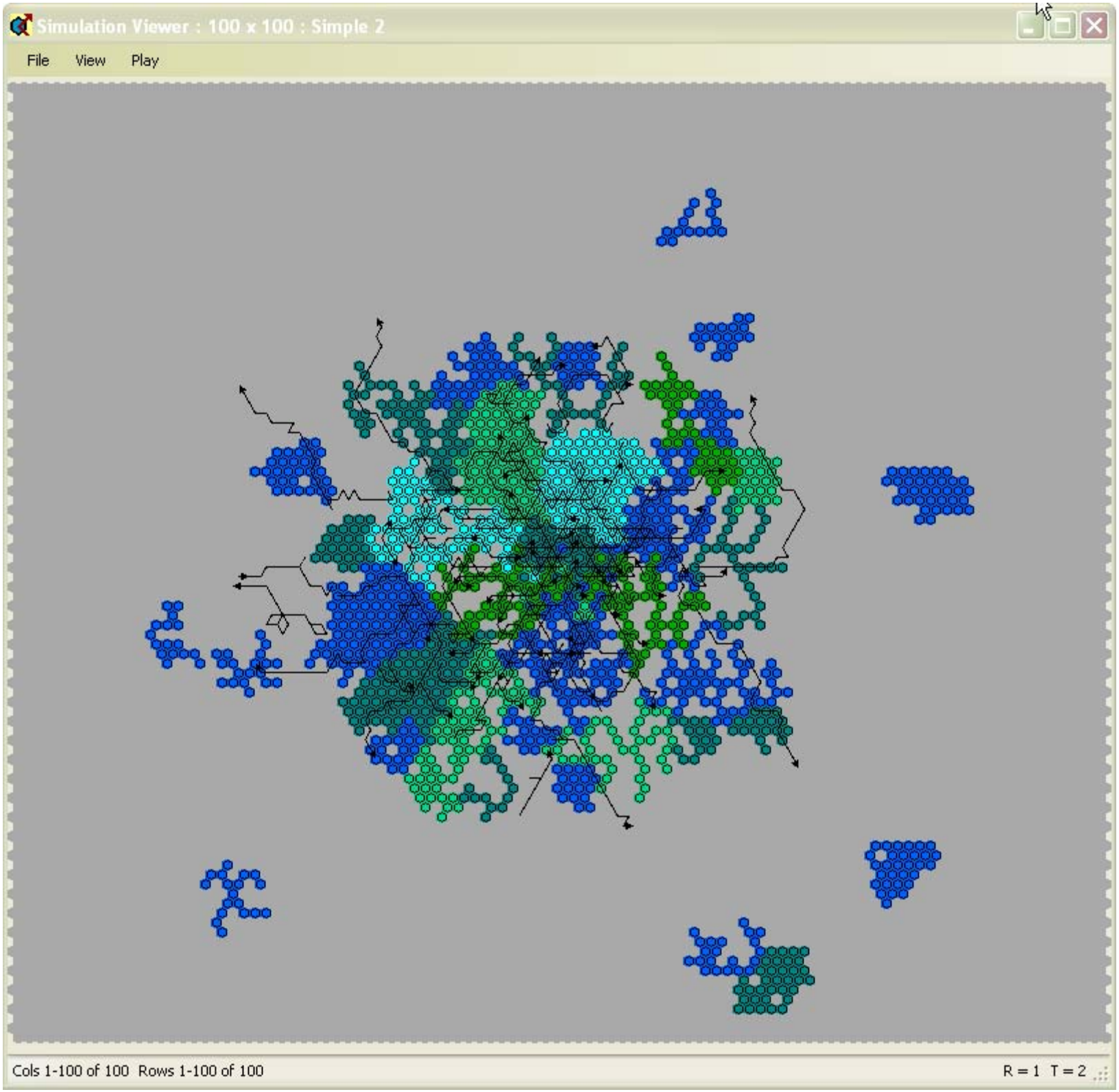
Both floaters and group members experience density-dependent growth and a carrying capacity

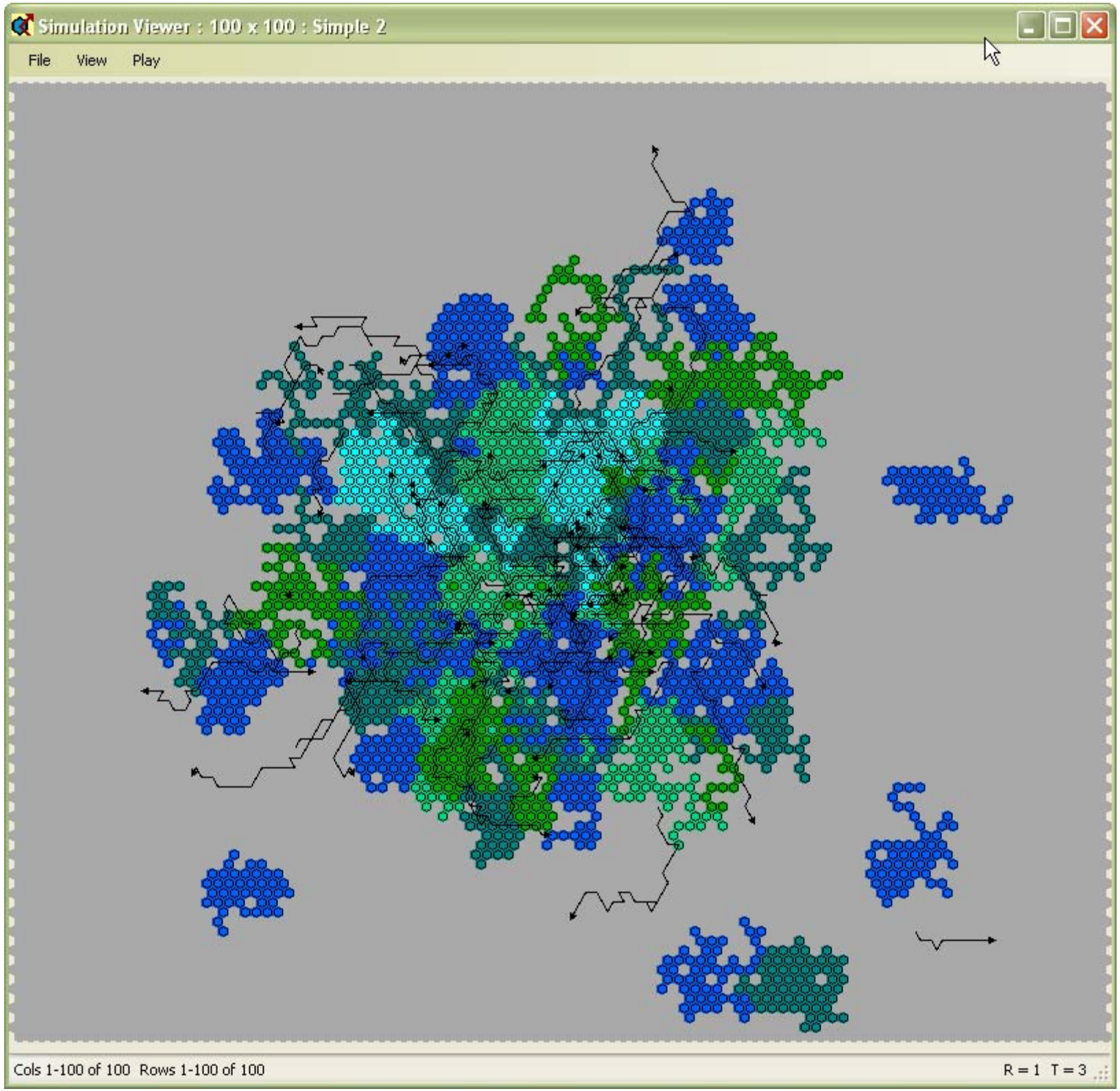
Population Growth Limited by Stage-Specific Reproduction and Survival, and by Area and Resource Availability

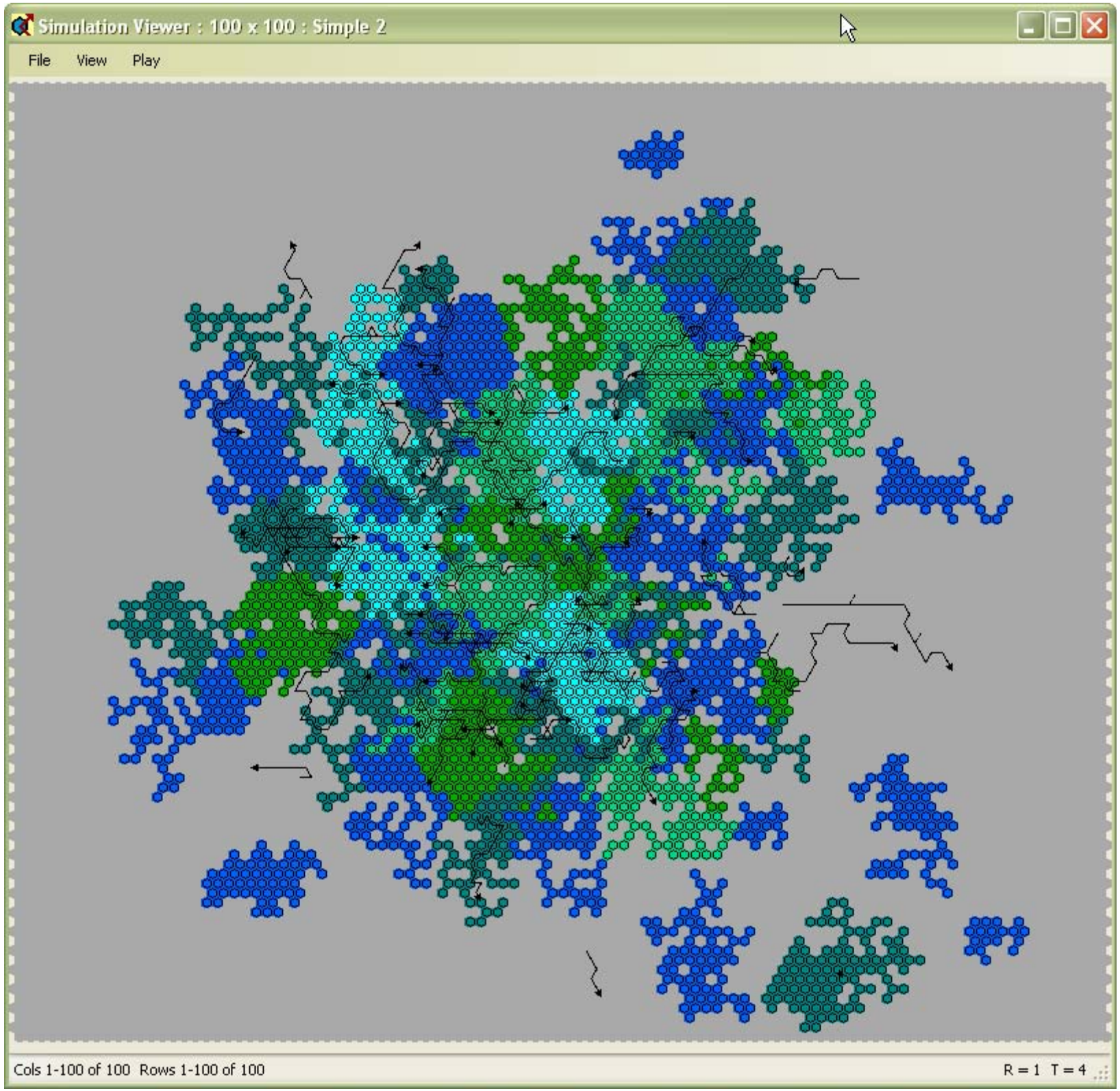


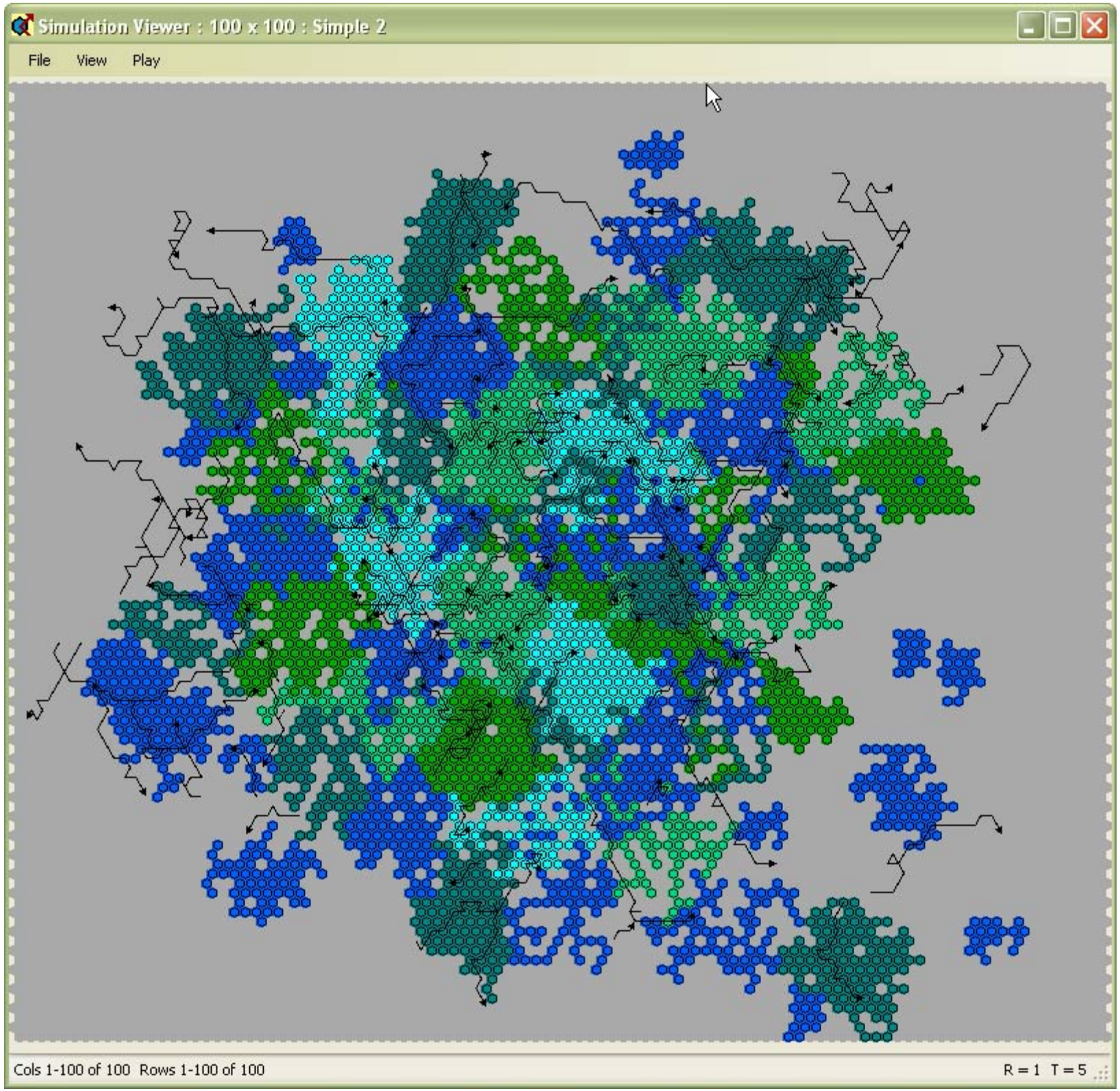

Population Growth Limited by
Stage-Specific Reproduction and Survival
and also by Area and Resource Availability
Number of Individuals
500
400
300
200
100
0
0
5
10
15
20
25
Time Step
Group Members
Floaters

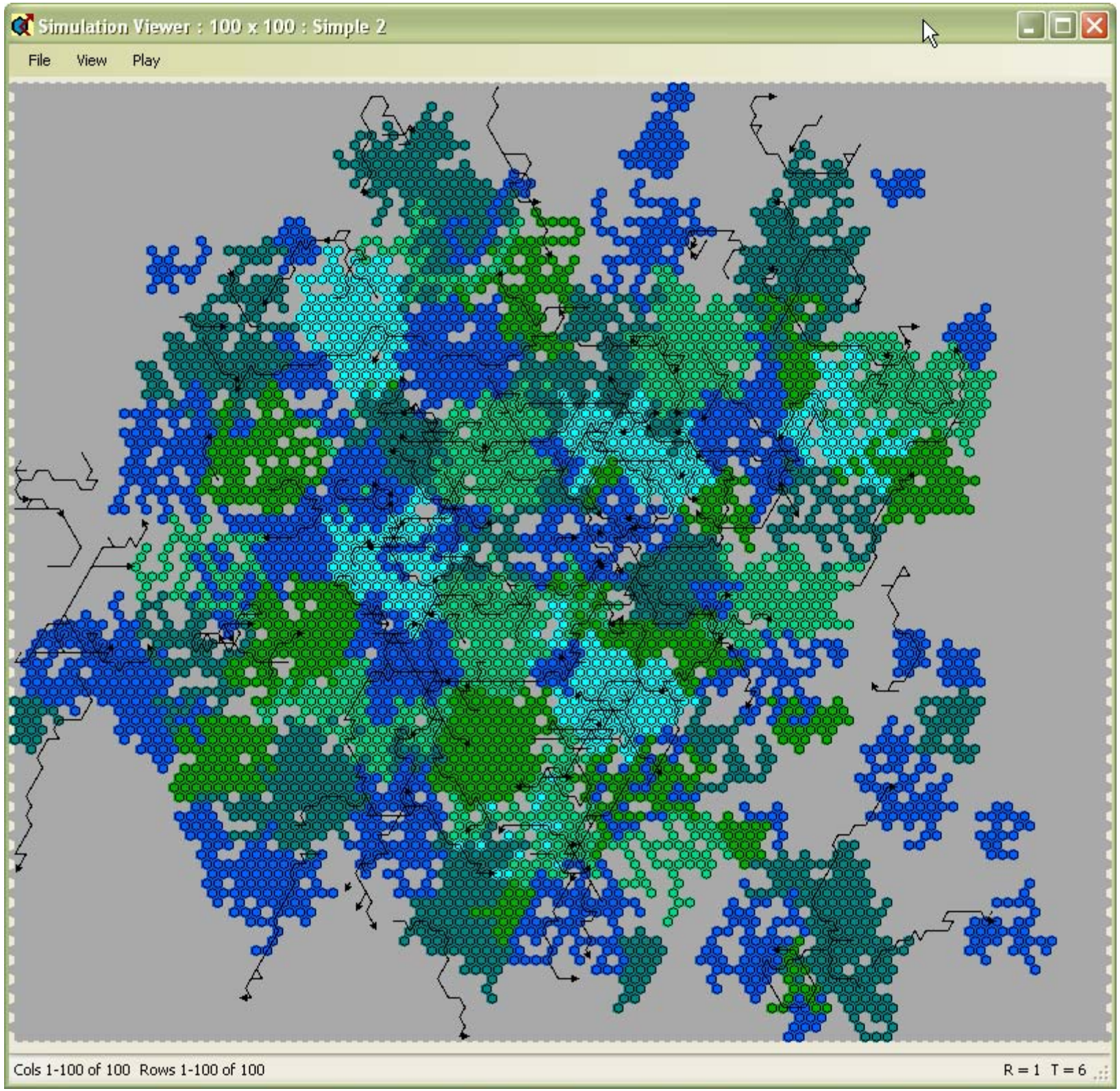

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 1

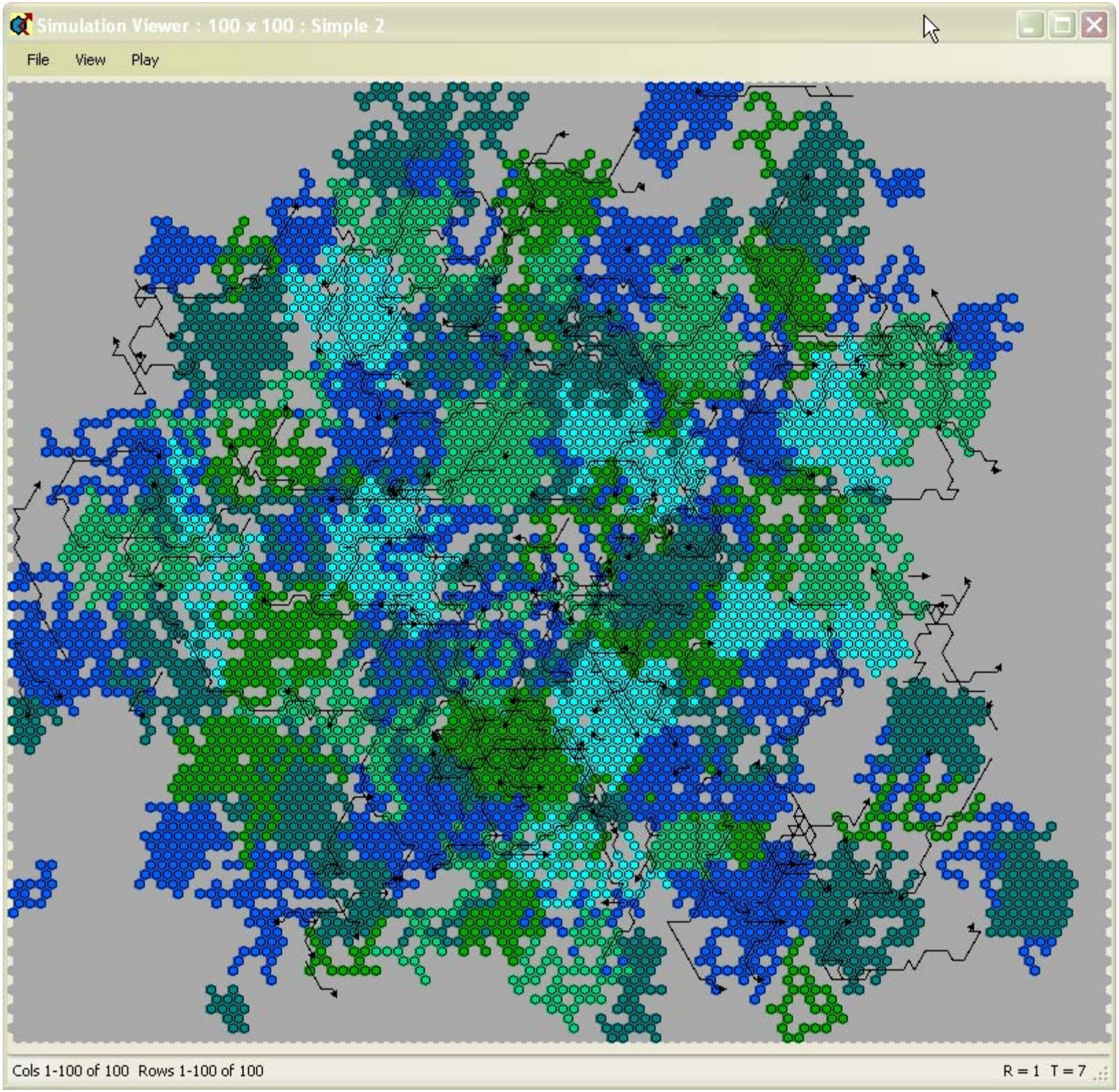

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 2

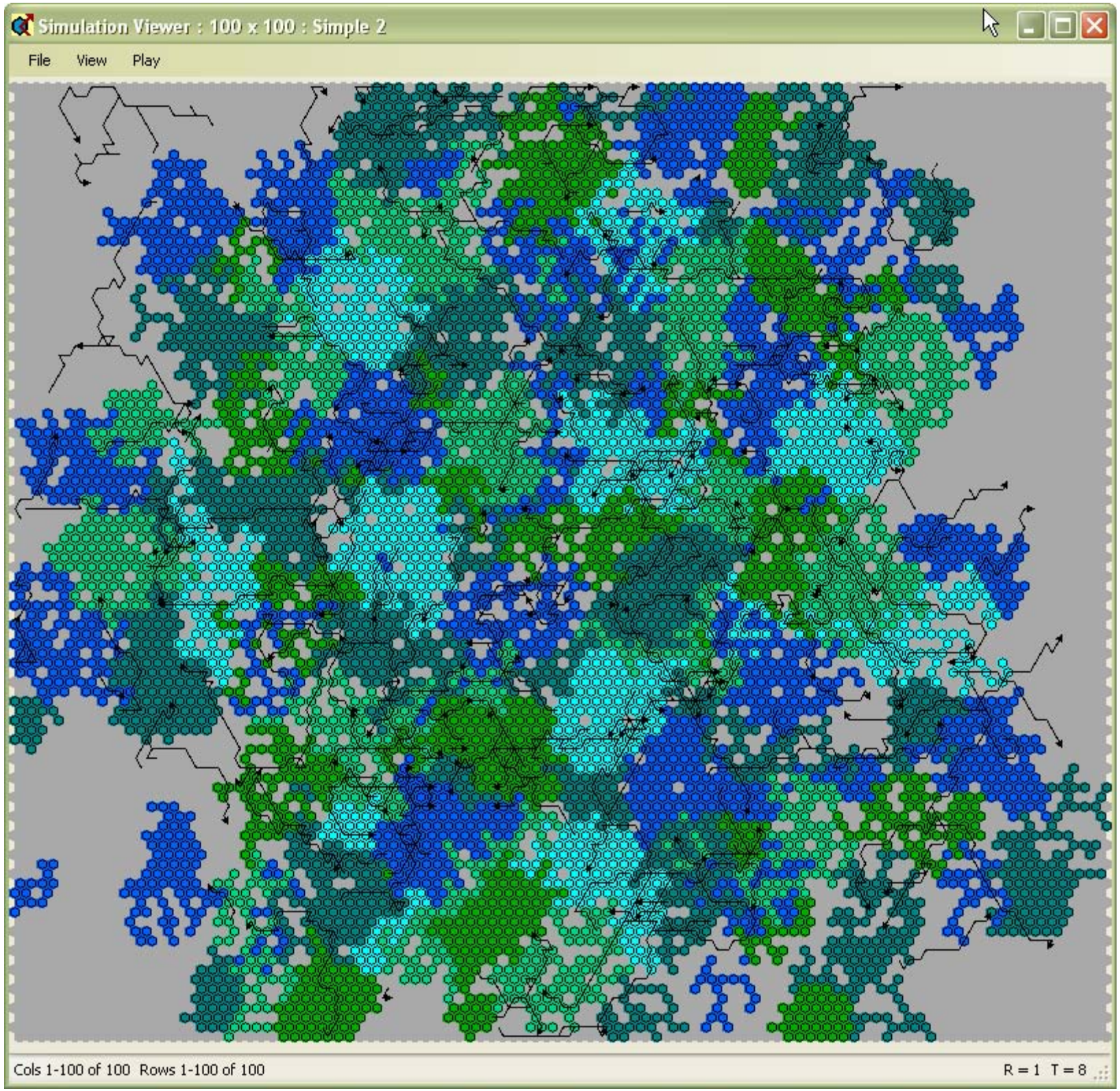

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 3

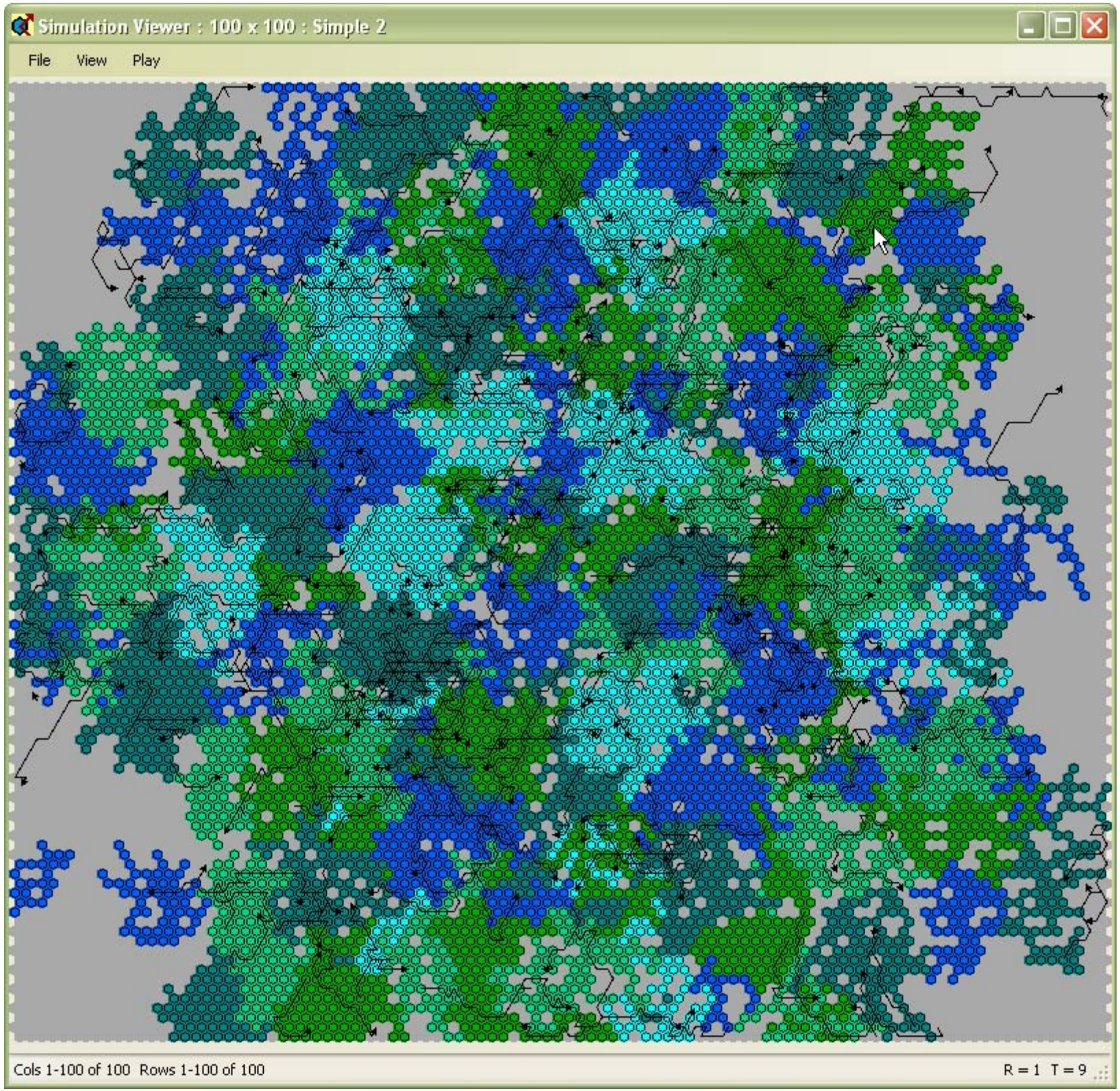

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 4

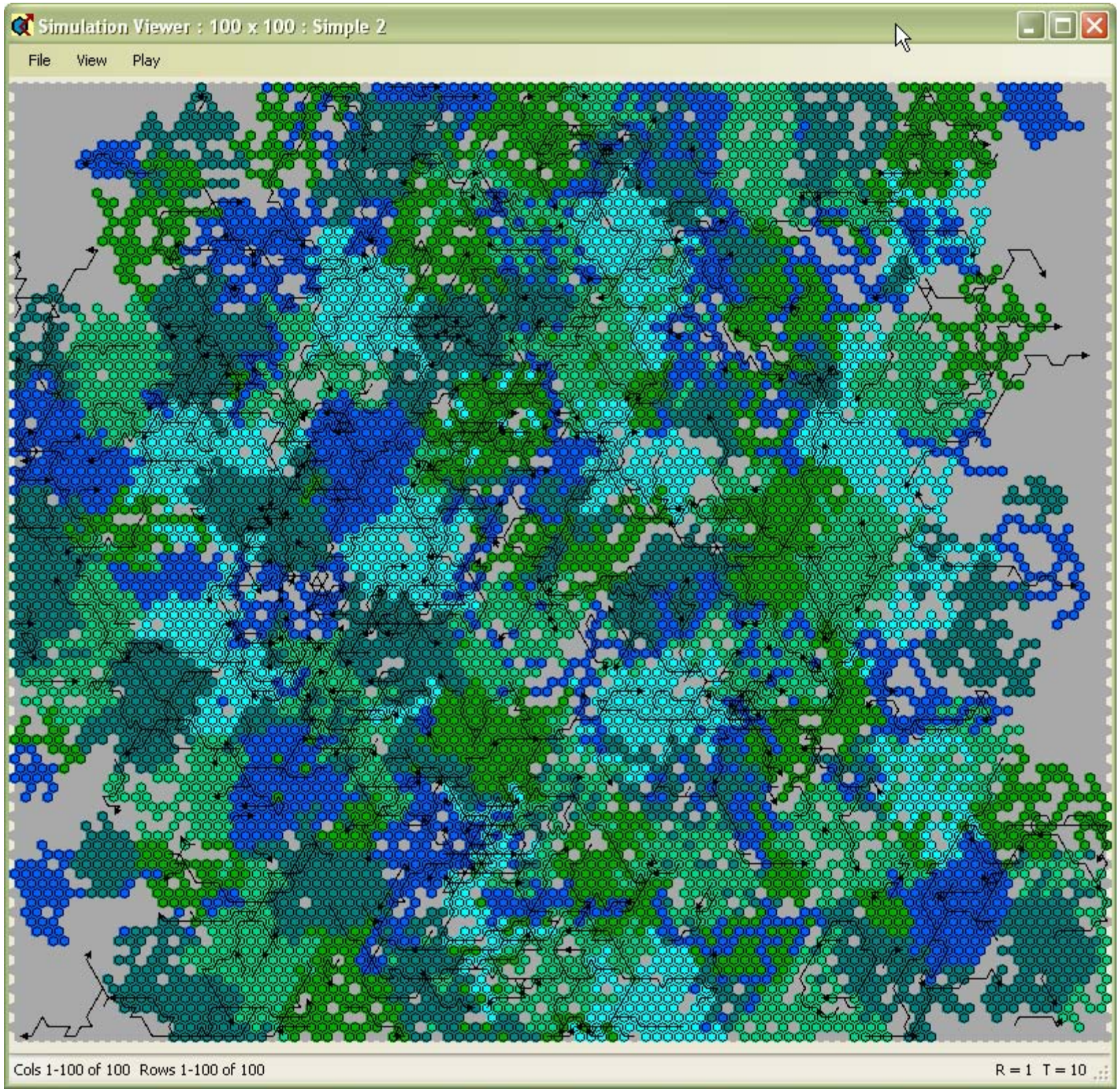

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 5

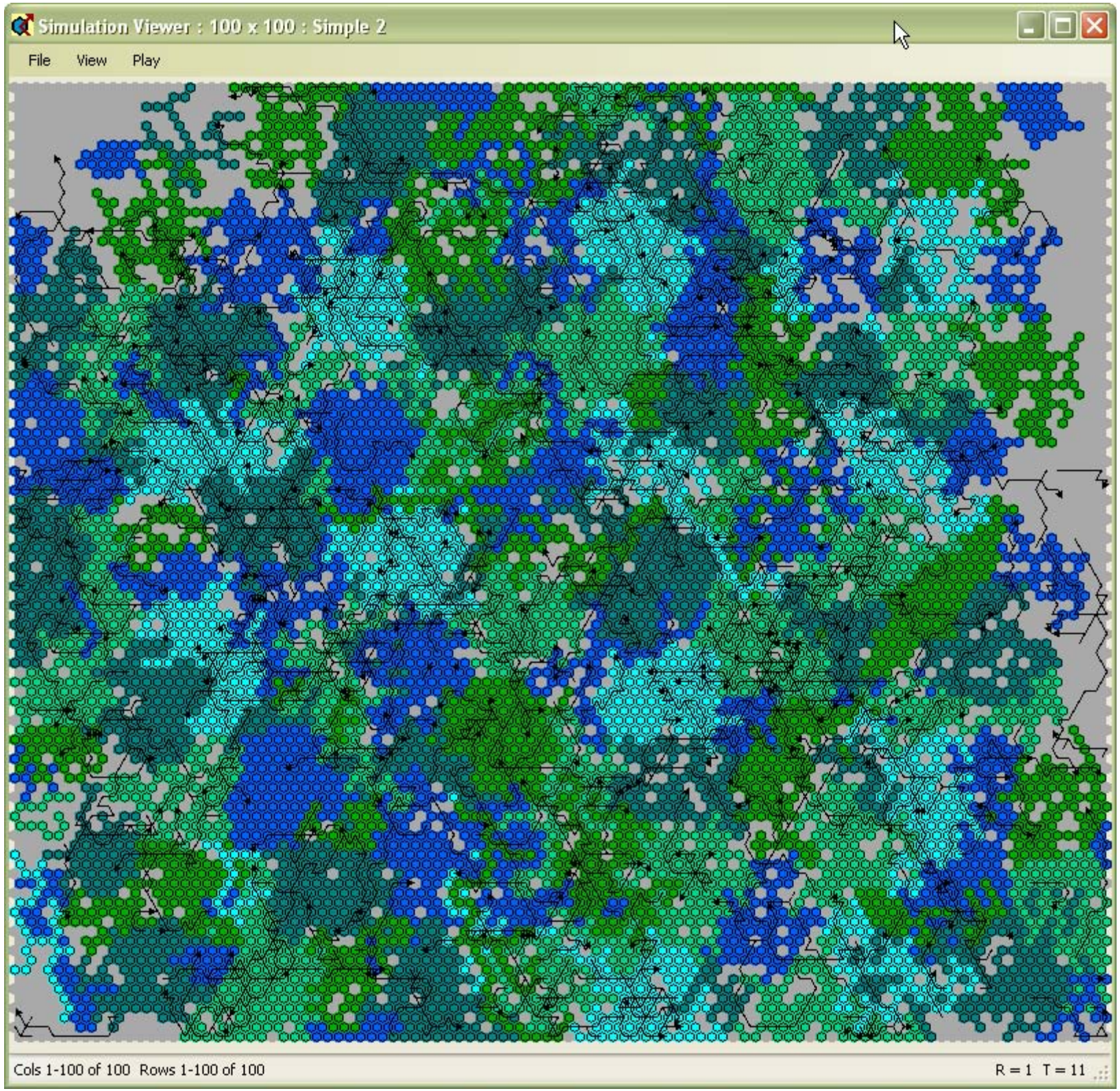

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 6

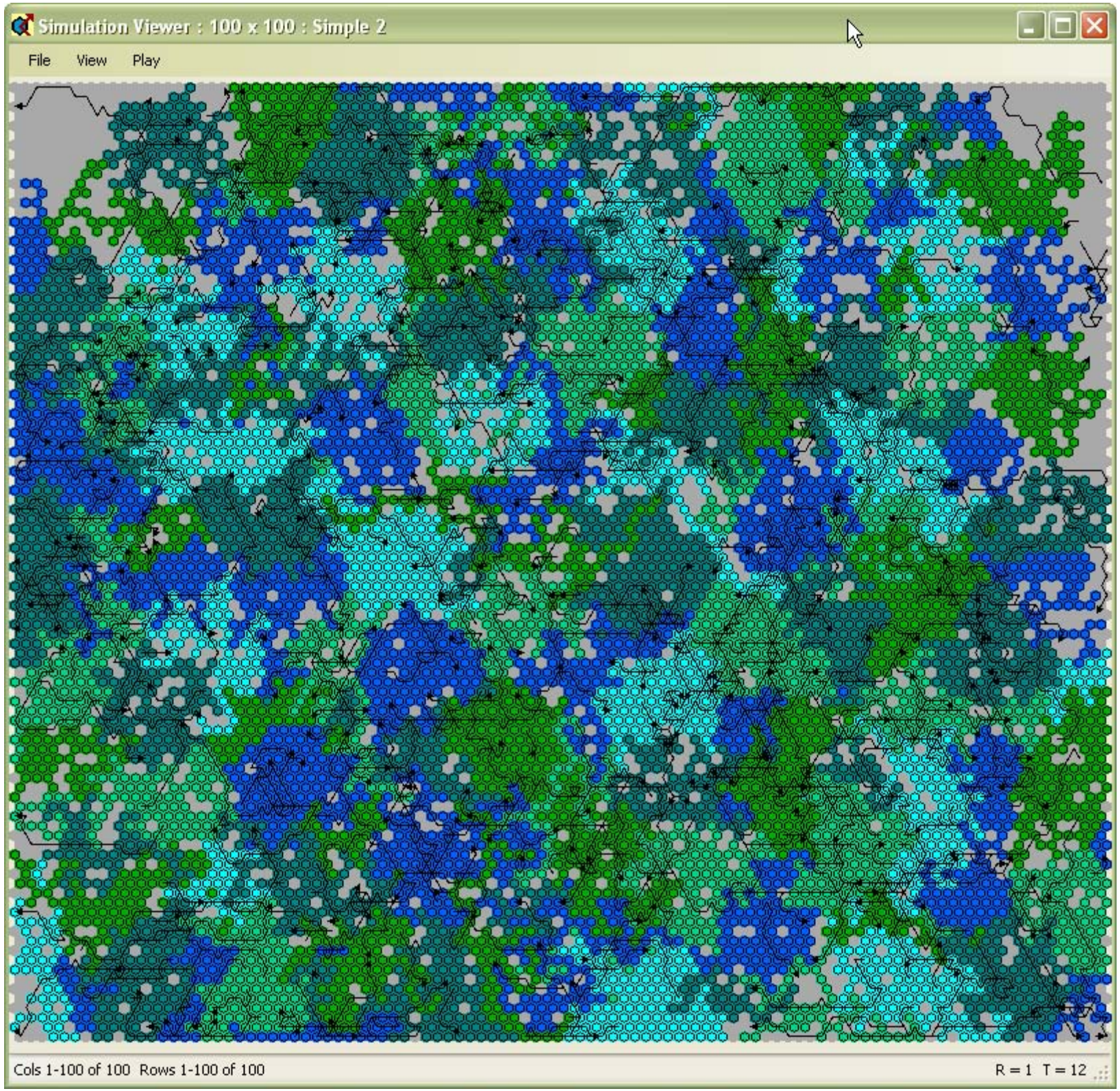

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 7

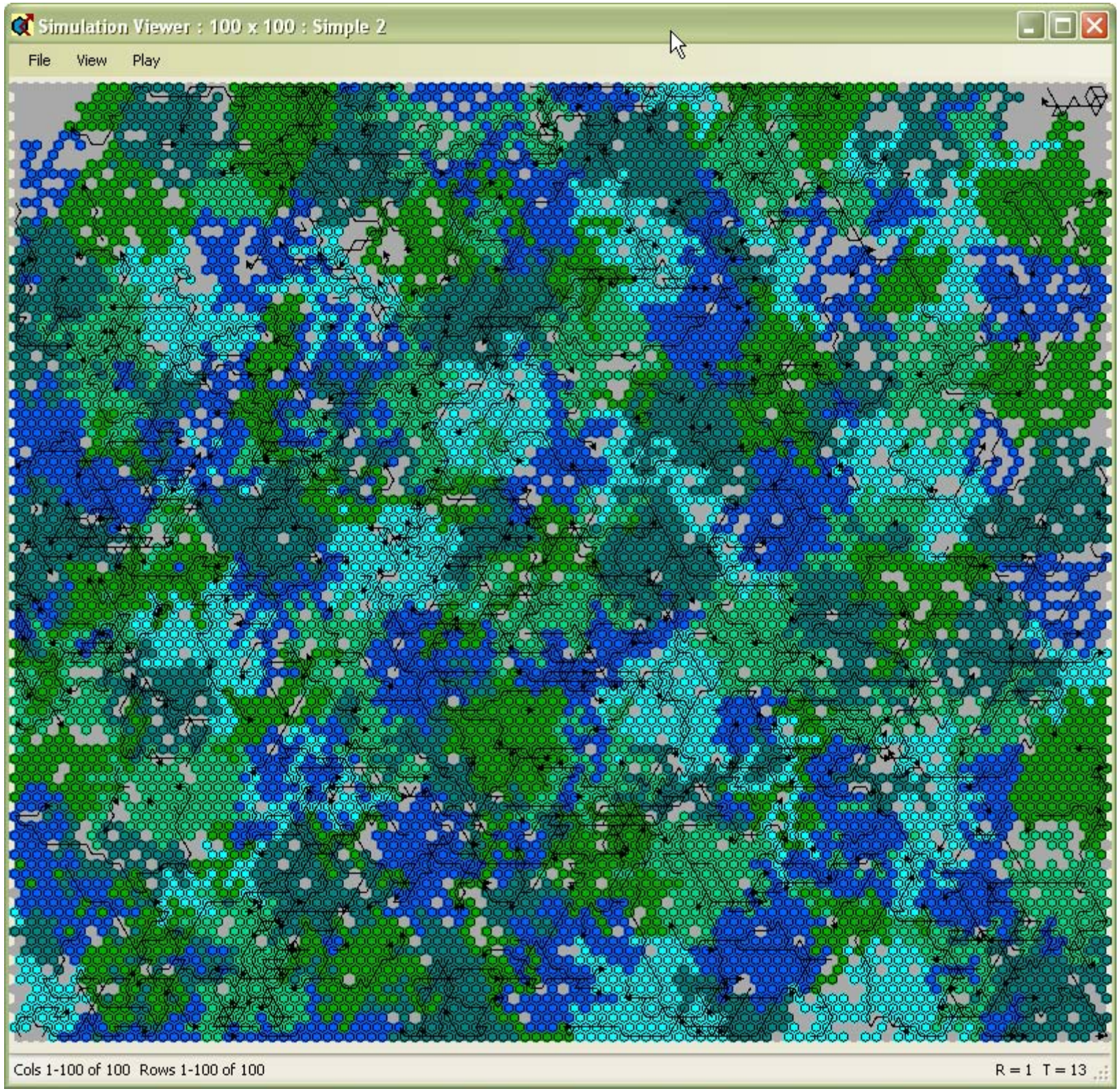

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 8

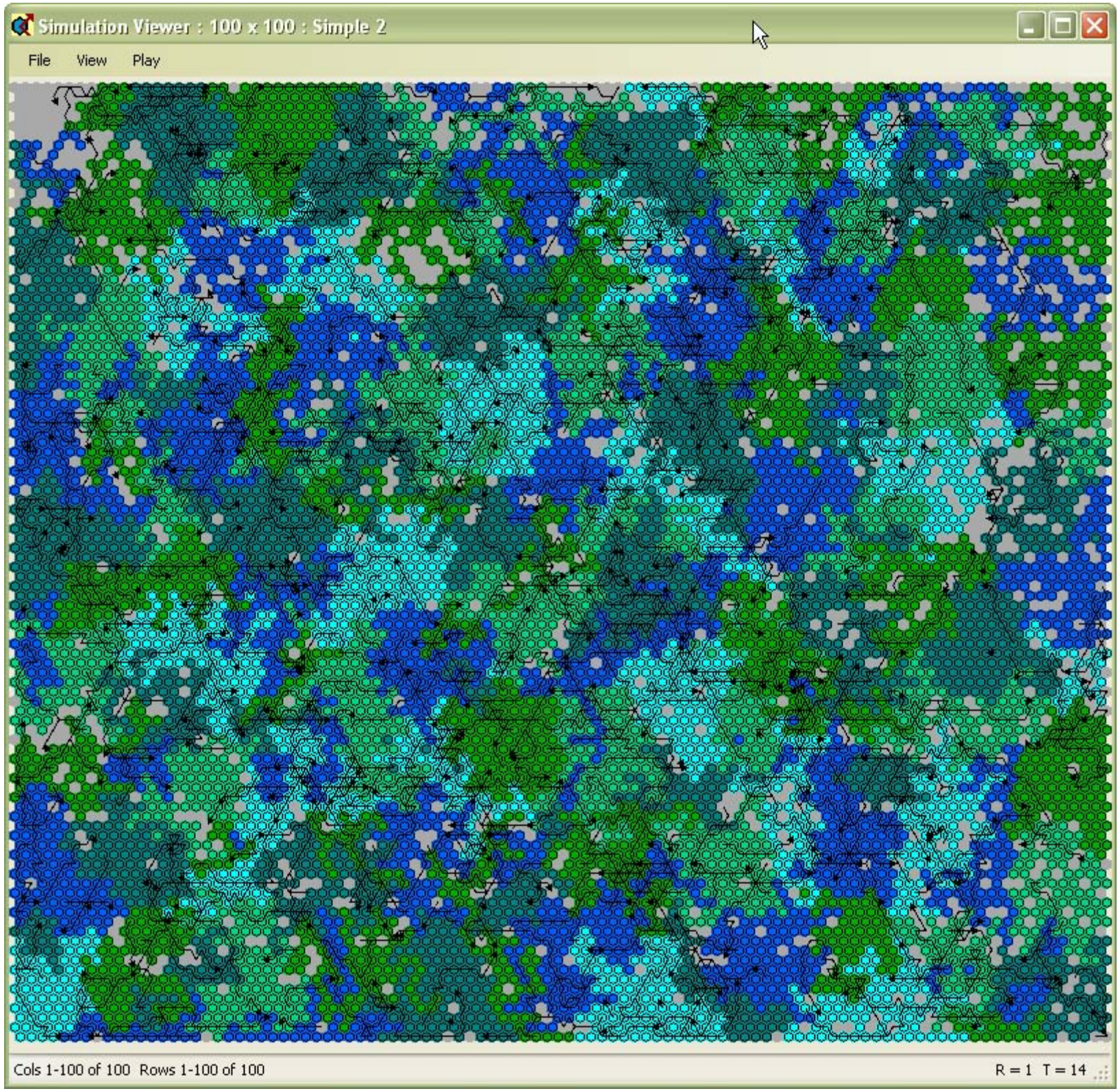

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 9

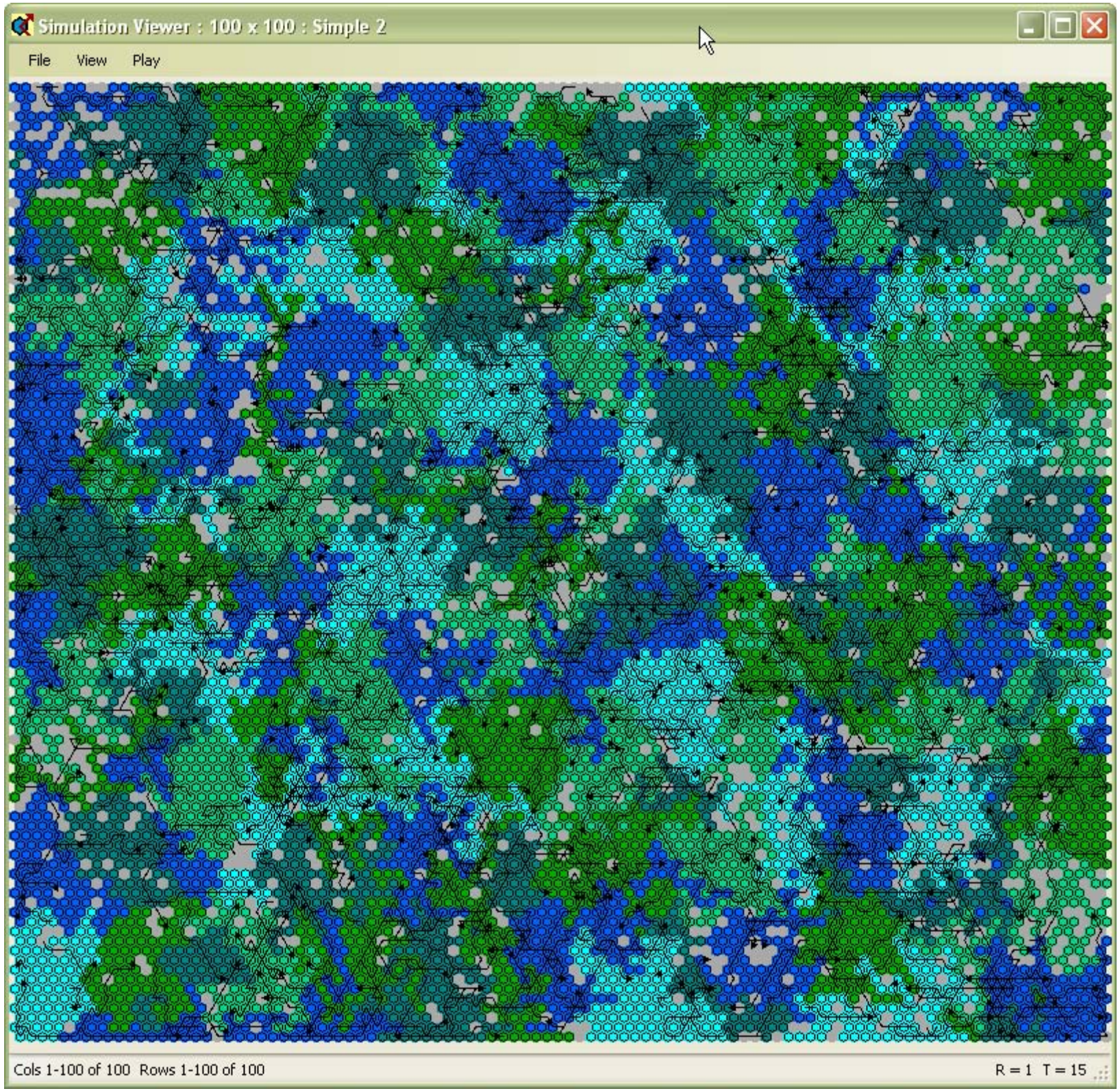

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 10


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 11


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 12


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 13


Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 14

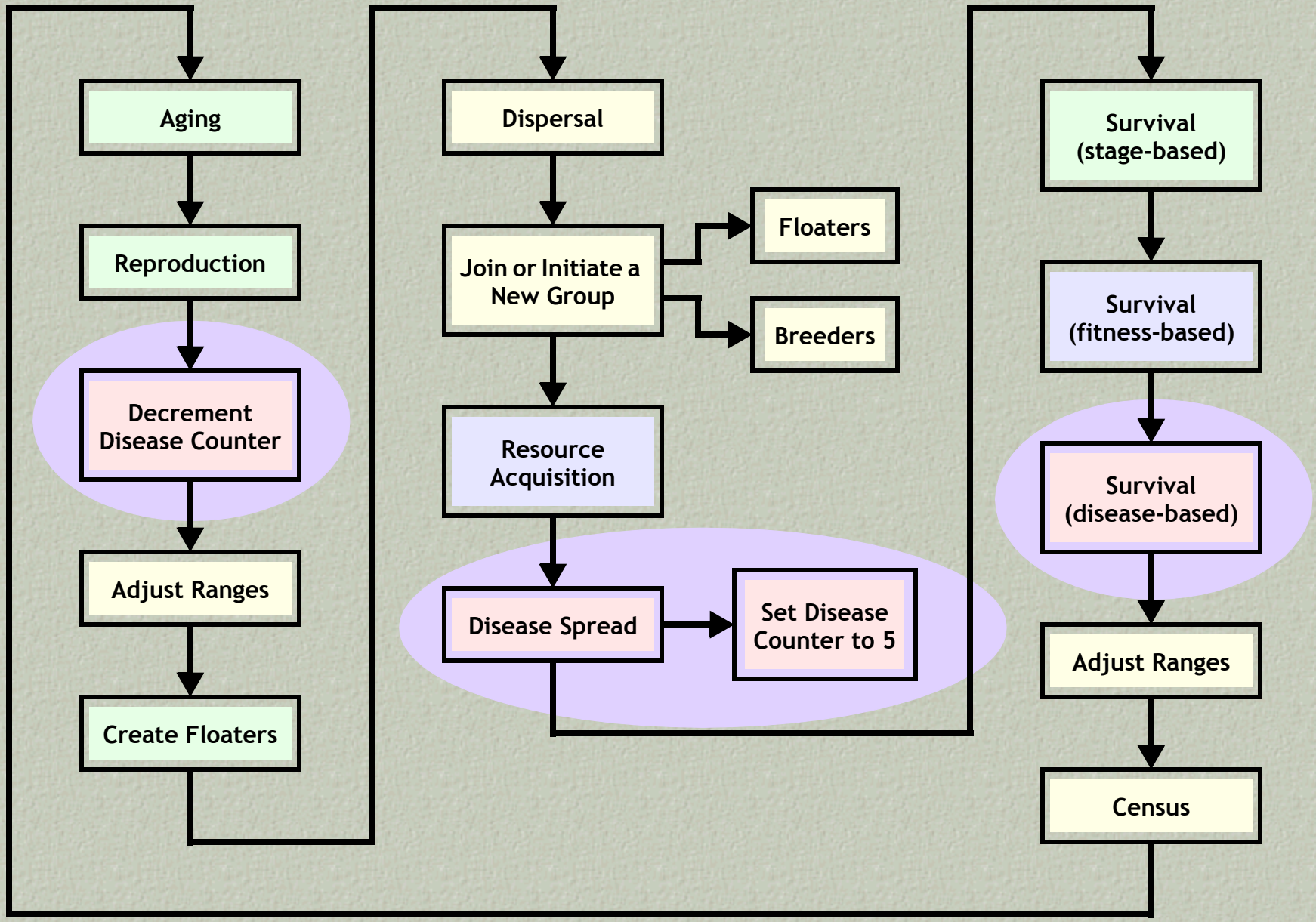

Simulation Viewer : 100 x 100 : Simple 2
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 15

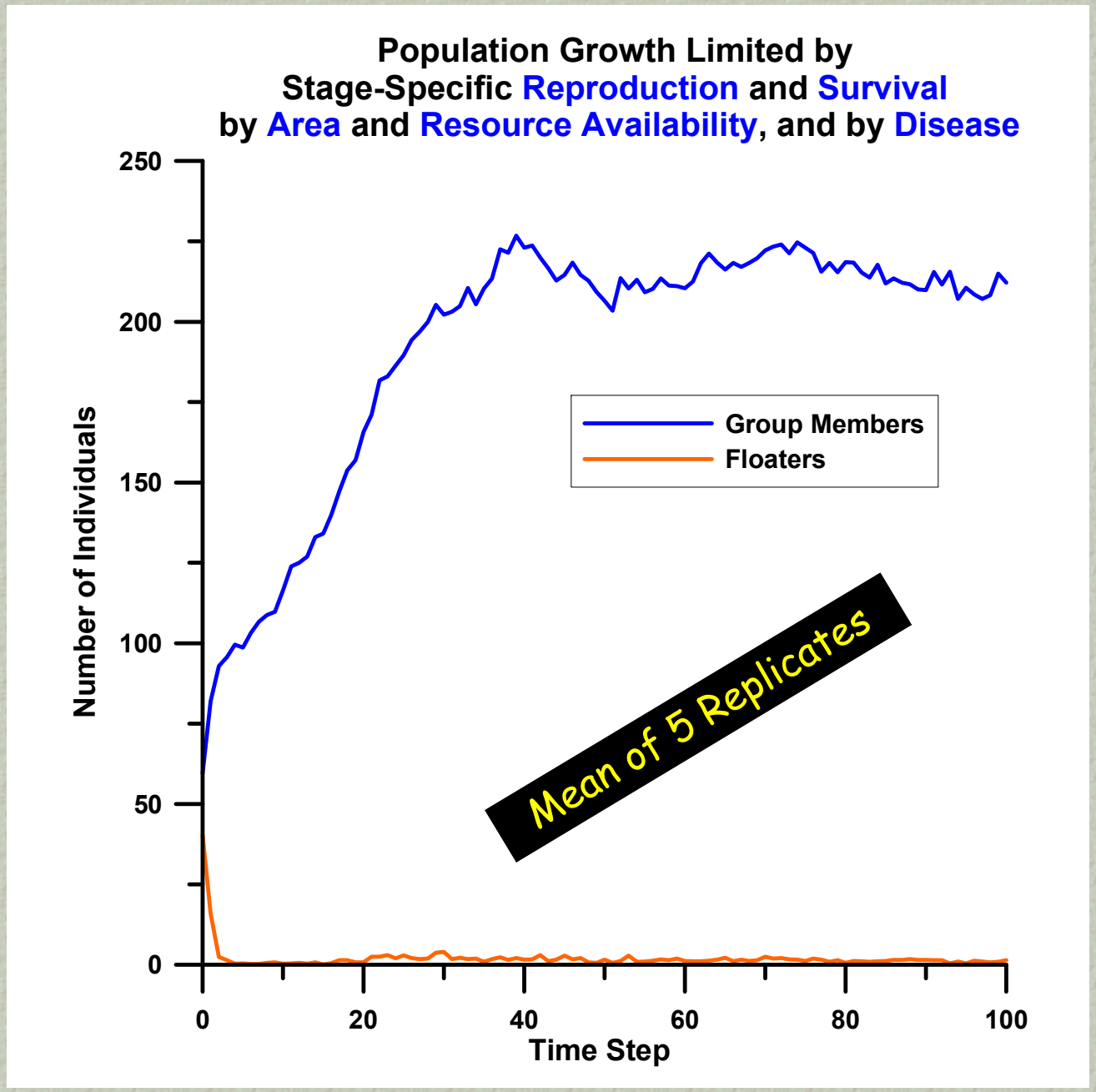
Add A Pseudo-Disease Component

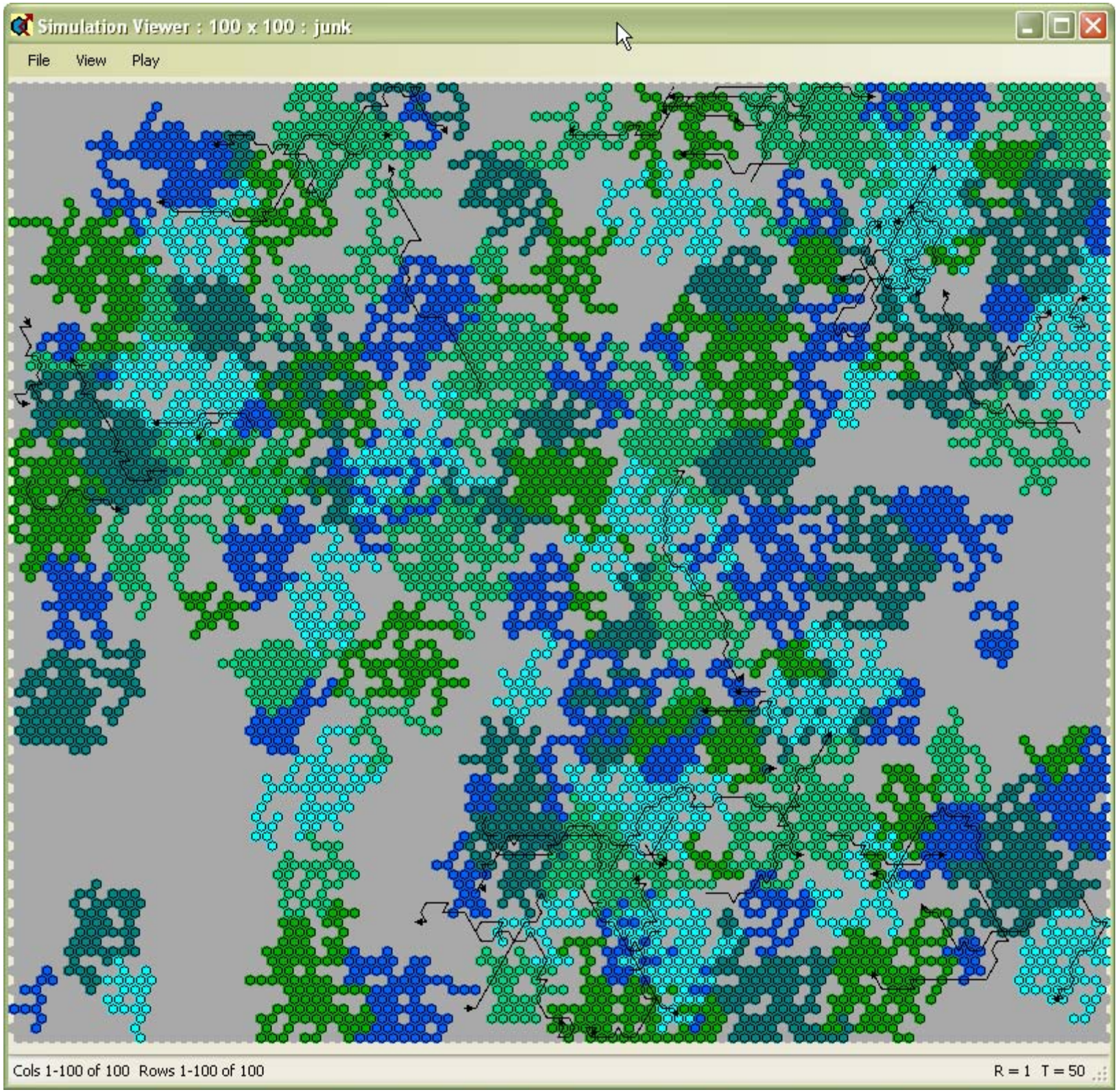
The disease model is over-simplified
It spreads from individual to individual
It takes >= 5 time steps to loose the infection

- The disease counter is decremented each time step
- Individuals are disease-free if the counter = 0
- The disease counter is set to 5 on exposure
- The disease is spread by birth and by contact

Population Growth Limited by Stage-Specific Reproduction and Survival, by Area and Resource Availability, and by Disease



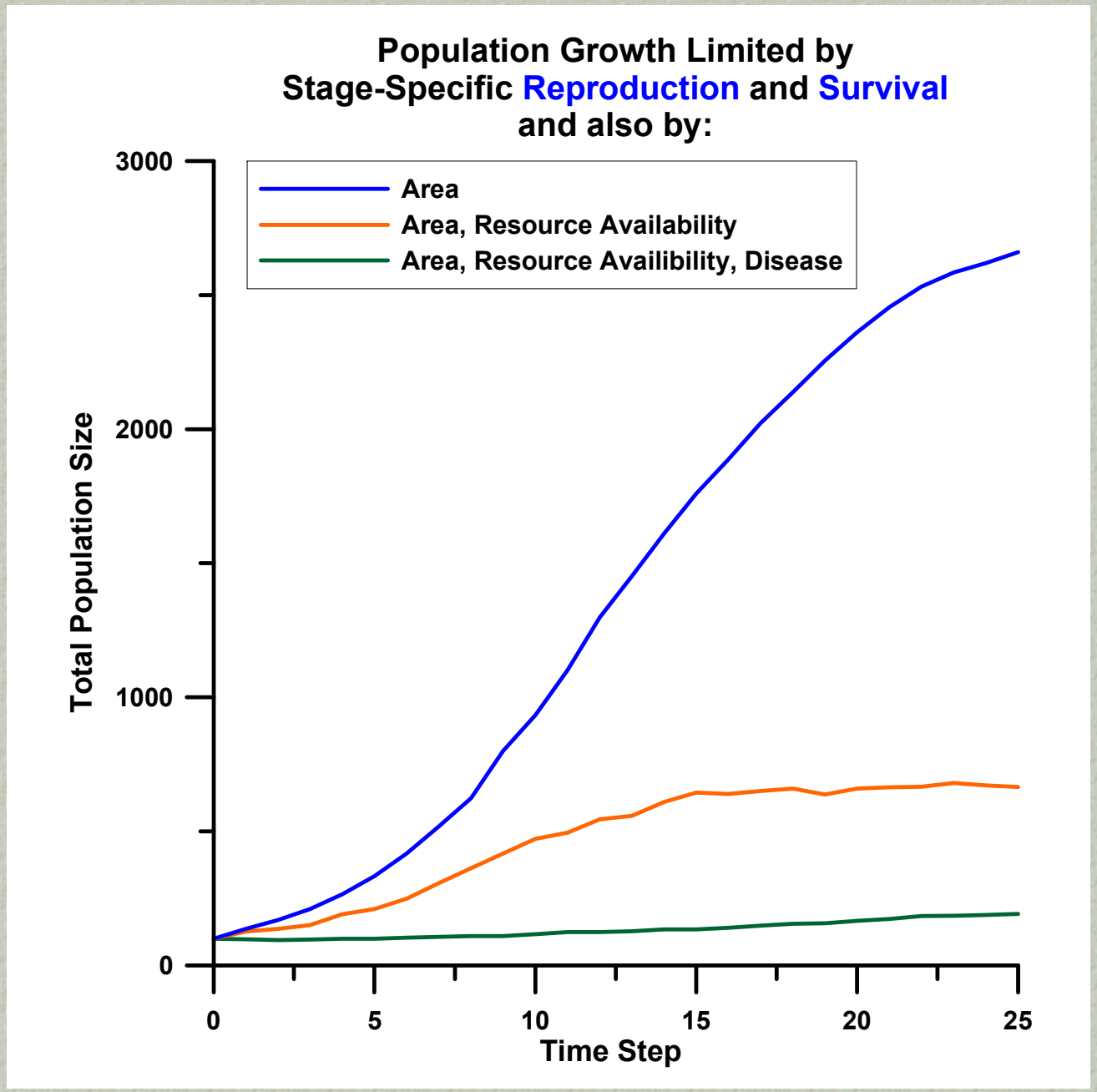

Population Growth Limited by
Stage-Specific Reproduction and Survival
by Area and Resource Availability, and by Disease
Number of Individuals
250
200
150
100
50
0
0
20
40
60
80
100
Time Step
Group Members
Floaters
Mean of 5 Replicates


Simulation Viewer : 100 x 100 : junk
File
View
Play
Cols 1-100 of 100 Rows 1-100 of 100
R = 1 T = 50

Quick Recap

We have compared four model structures:
Population growth limited by:

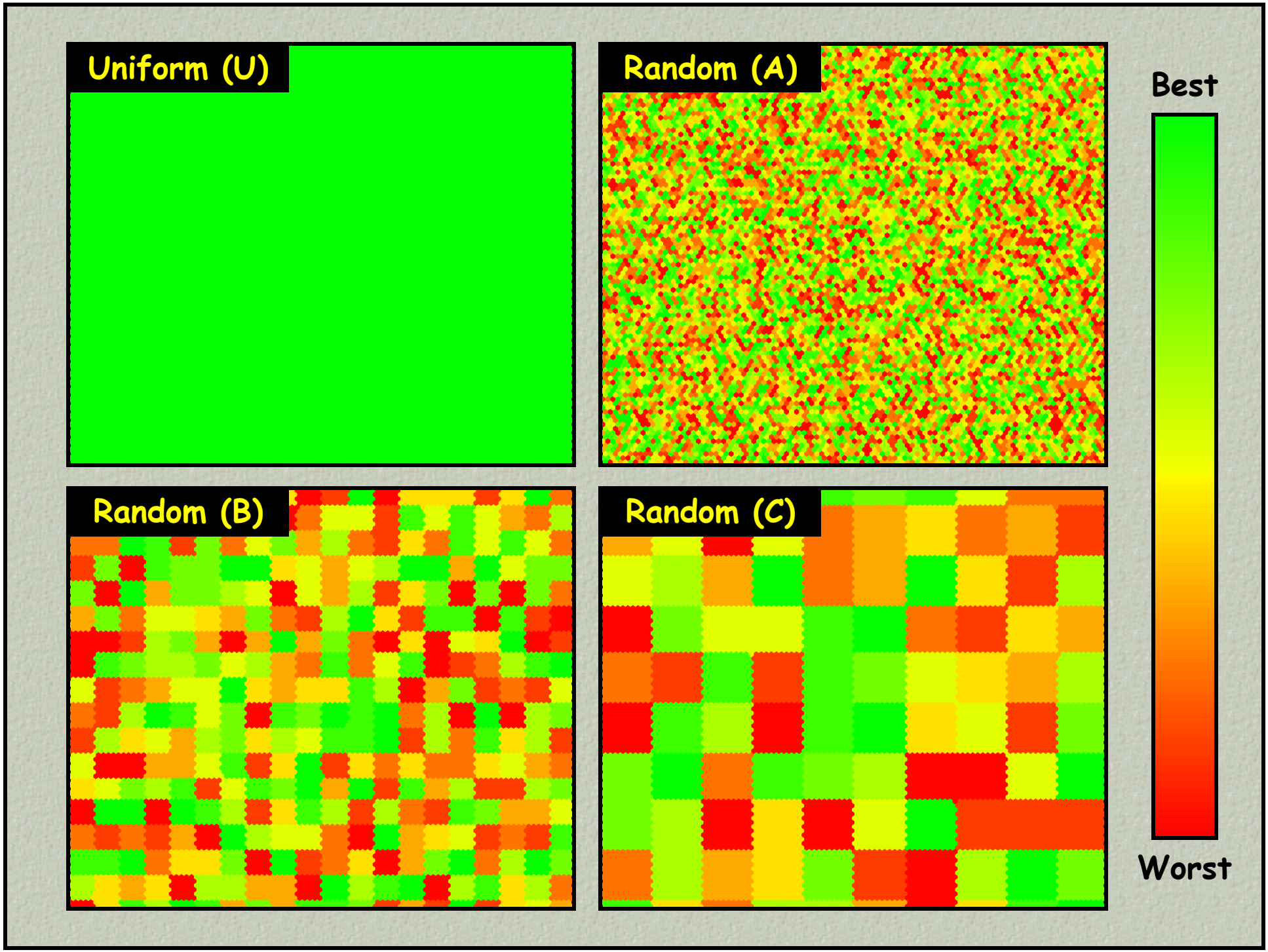
- Stage-specific survival and reproduction
- Plus area (space is limited)
- Plus resources (resource availability is limited)
- Plus disease (which can impact survival rates)

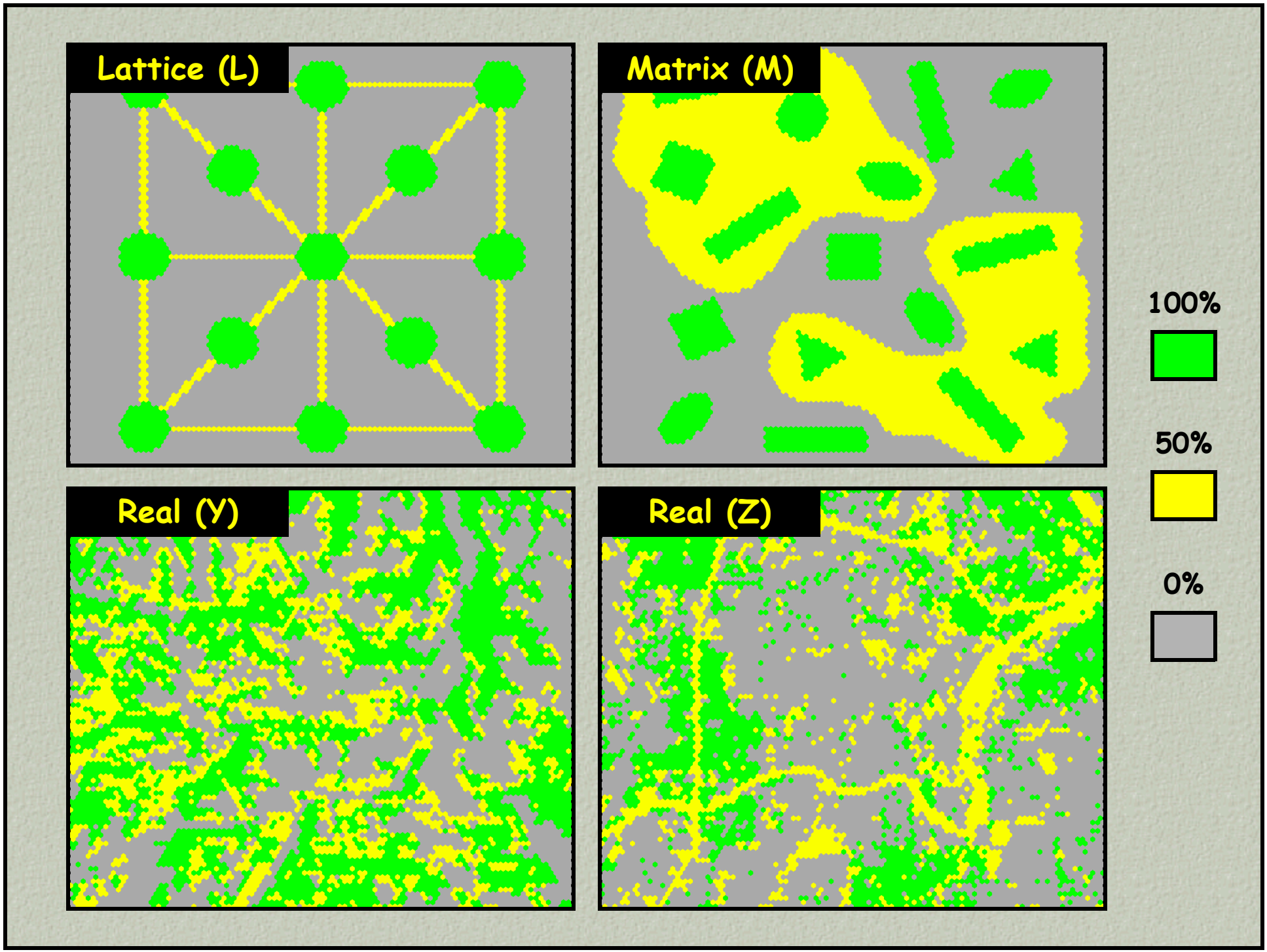

Population Growth Limited by
Stage-Specific Reproduction and Survival
and also by:
Area
Area, Resource Availability
Area, Resource Availibility, Disease
Total Population Size
3000
2000
1000
0
0
5
10
15
20
25
Time Step

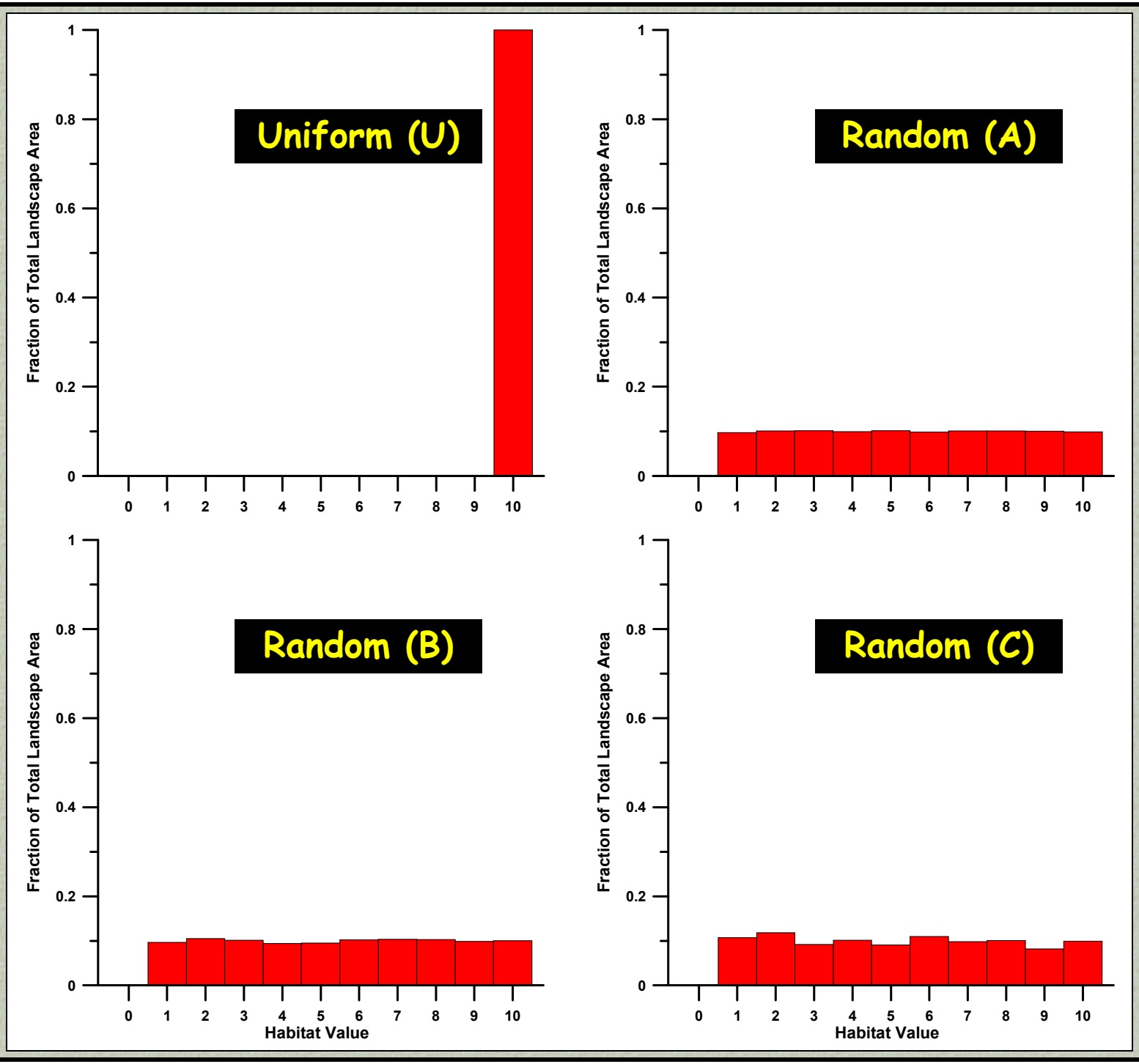
Now On To Spatial Structure

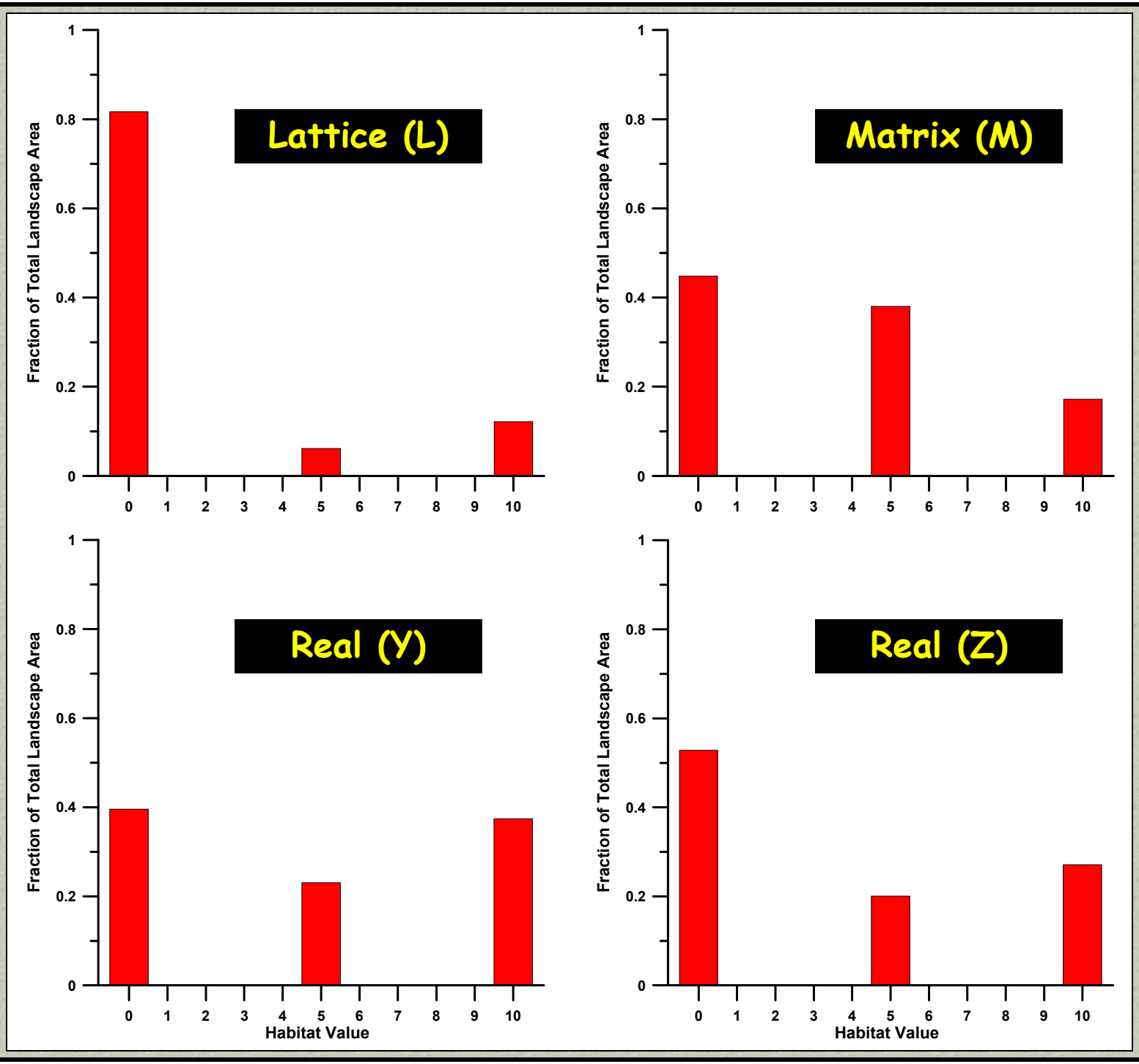
All of the previous results were generated
in a 100 x 100 hexagon landscape made up
of exclusively perfect quality habitat

- Habitat quality may vary from useless to ideal
- The quality spectrum may be more or less continuous
- Landscape structure may be simple or complex


Uniform (U)
Random (A)
Random (B)
Random (C)
Best
Worst


Lattice (L)
Matrix (M)
Real (Y)
Real (Z)
100%
50%
0%


Uniform (U)
Random (A)
Random (B)
Random (C)
Fraction of Total Landscape Area
Habitat Value
0
0.2
0.4
0.6
0.8
1
0 1 2 3 4 5 6 7 8 9 10

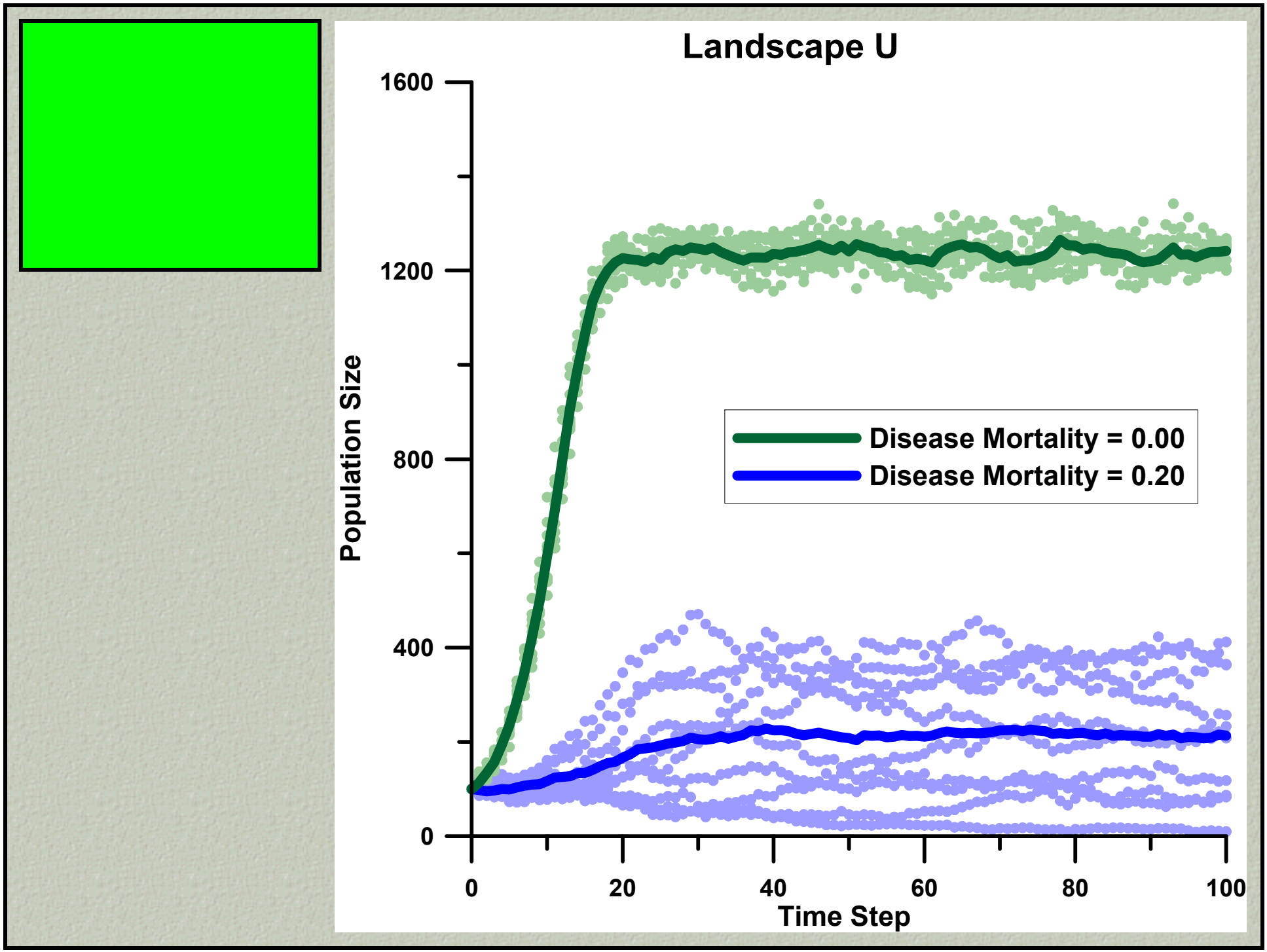

Lattice (L)
Matrix (M)
Real (Y)
Real (Z)
Fraction of Total Landscape Area
Habitat Value
0
0.2
0.4
0.6
0.8
1
0 1 2 3 4 5 6 7 8 9 10

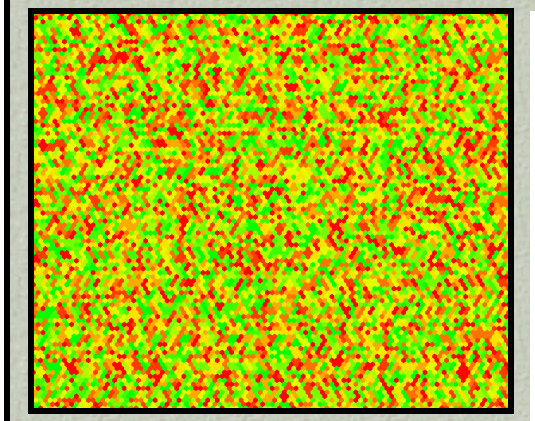
A Series Of Landscape Comparisons

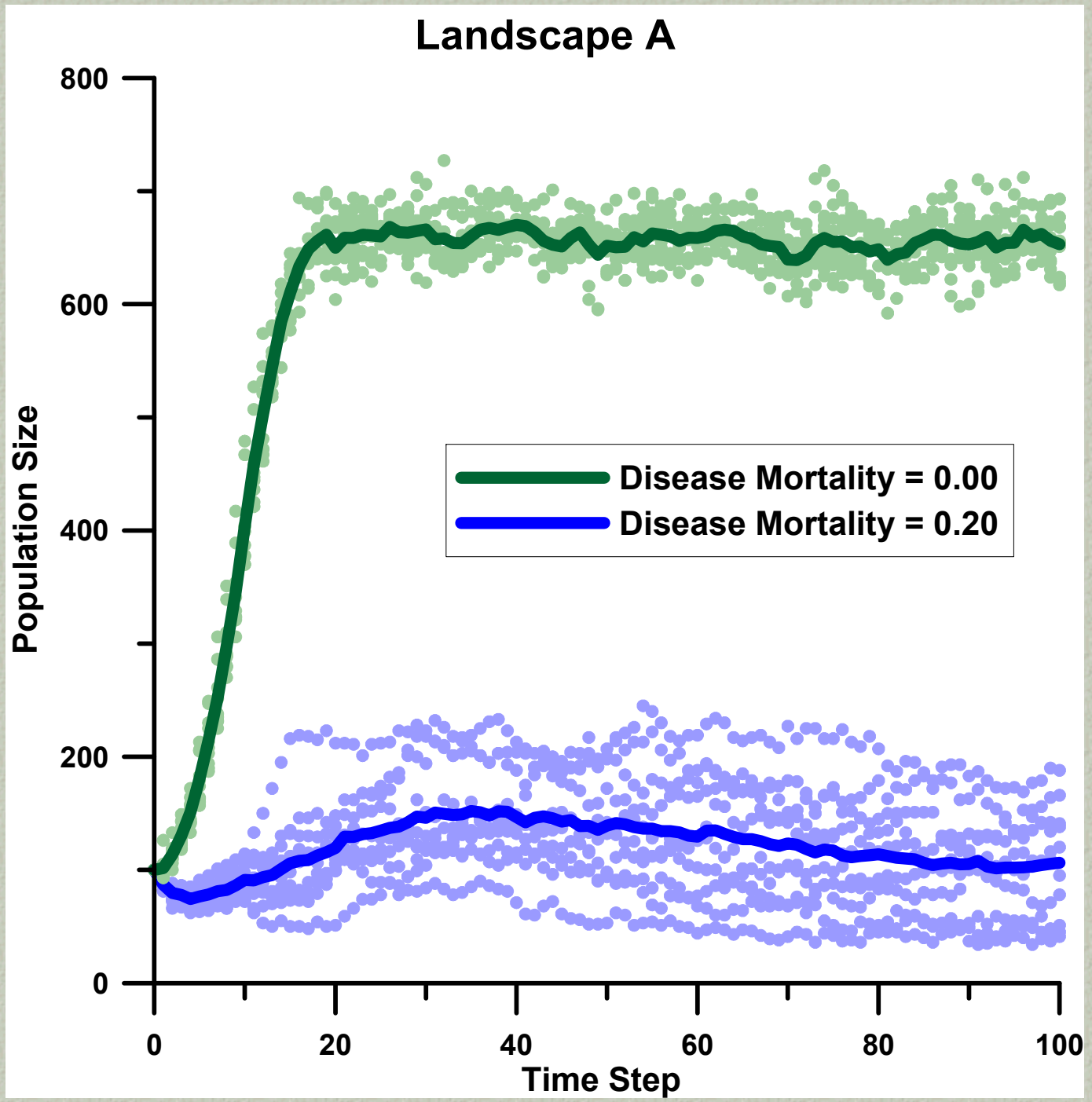
➔ **Population Size** ←

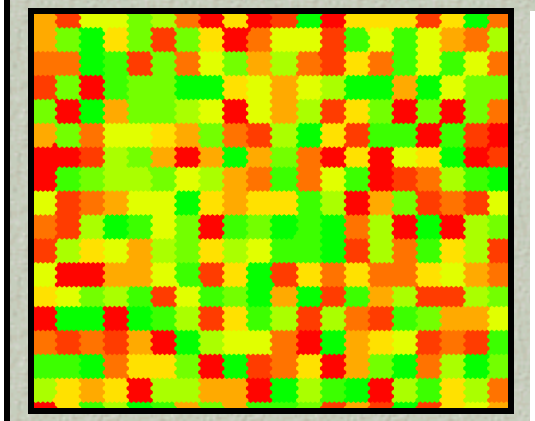
Each simulation consists of 5 replicates
of 100 time steps (years)
Means, and variability are illustrated

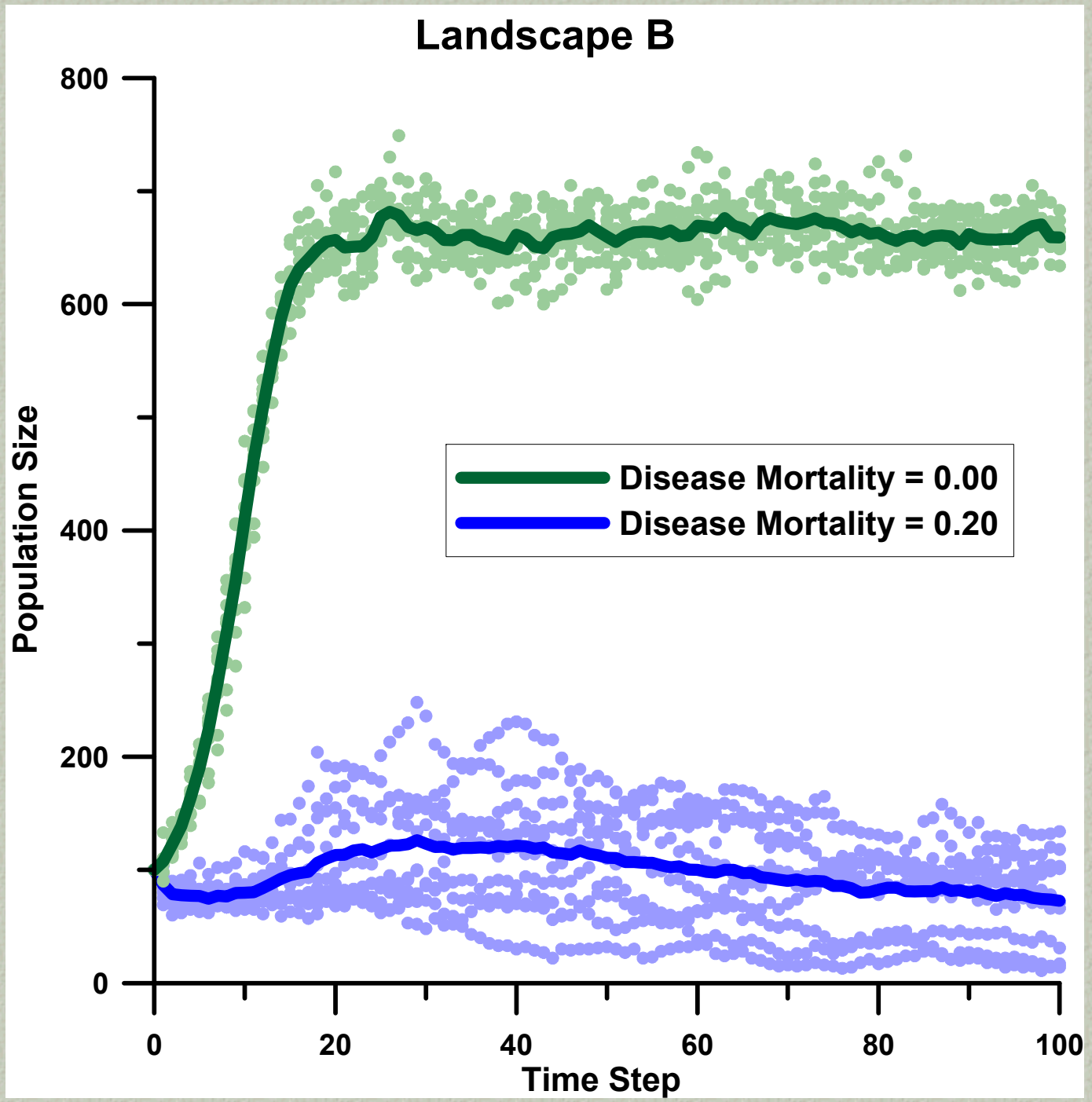
For each landscape, a simulation was run with
Disease mortality = 0%
Disease mortality = 20%

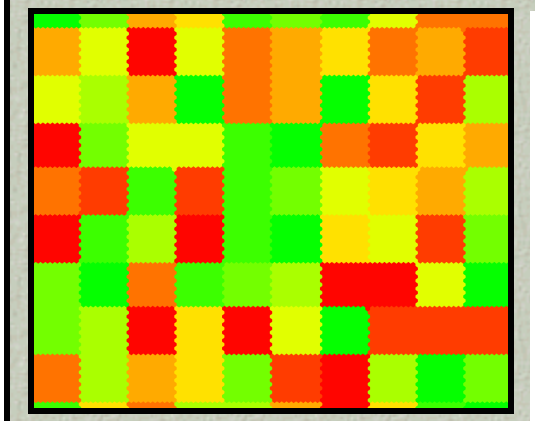

Landscape U
1600
1200
800
400
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

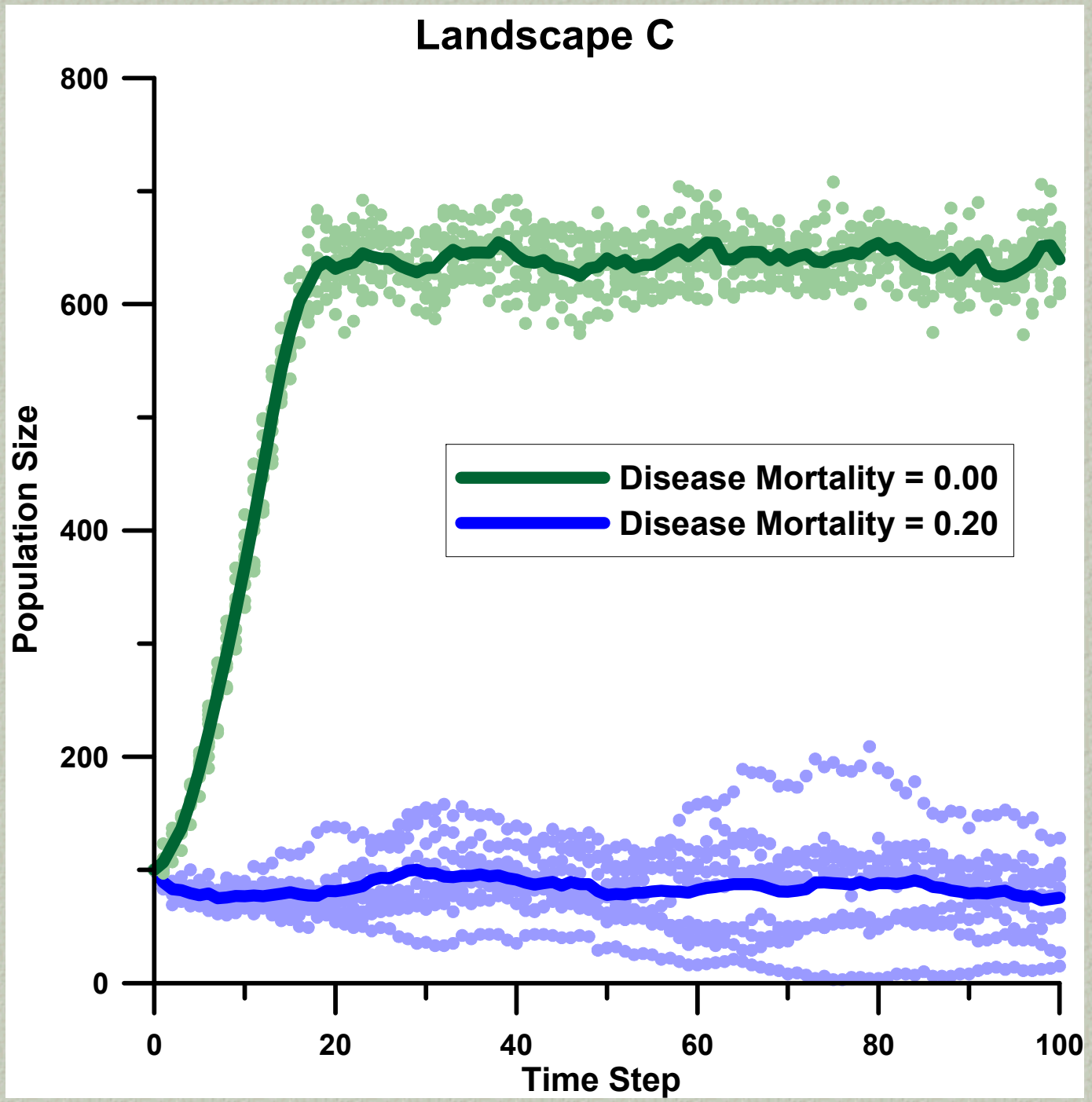


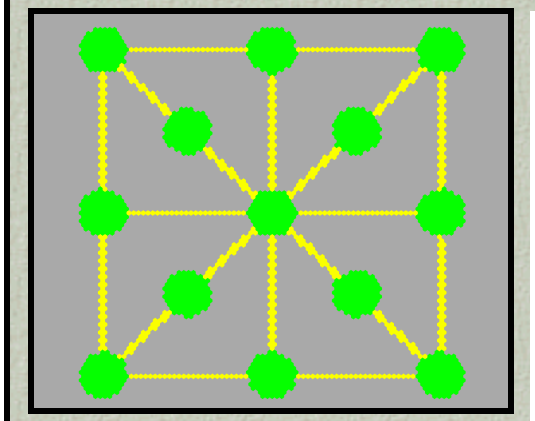

Landscape A
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

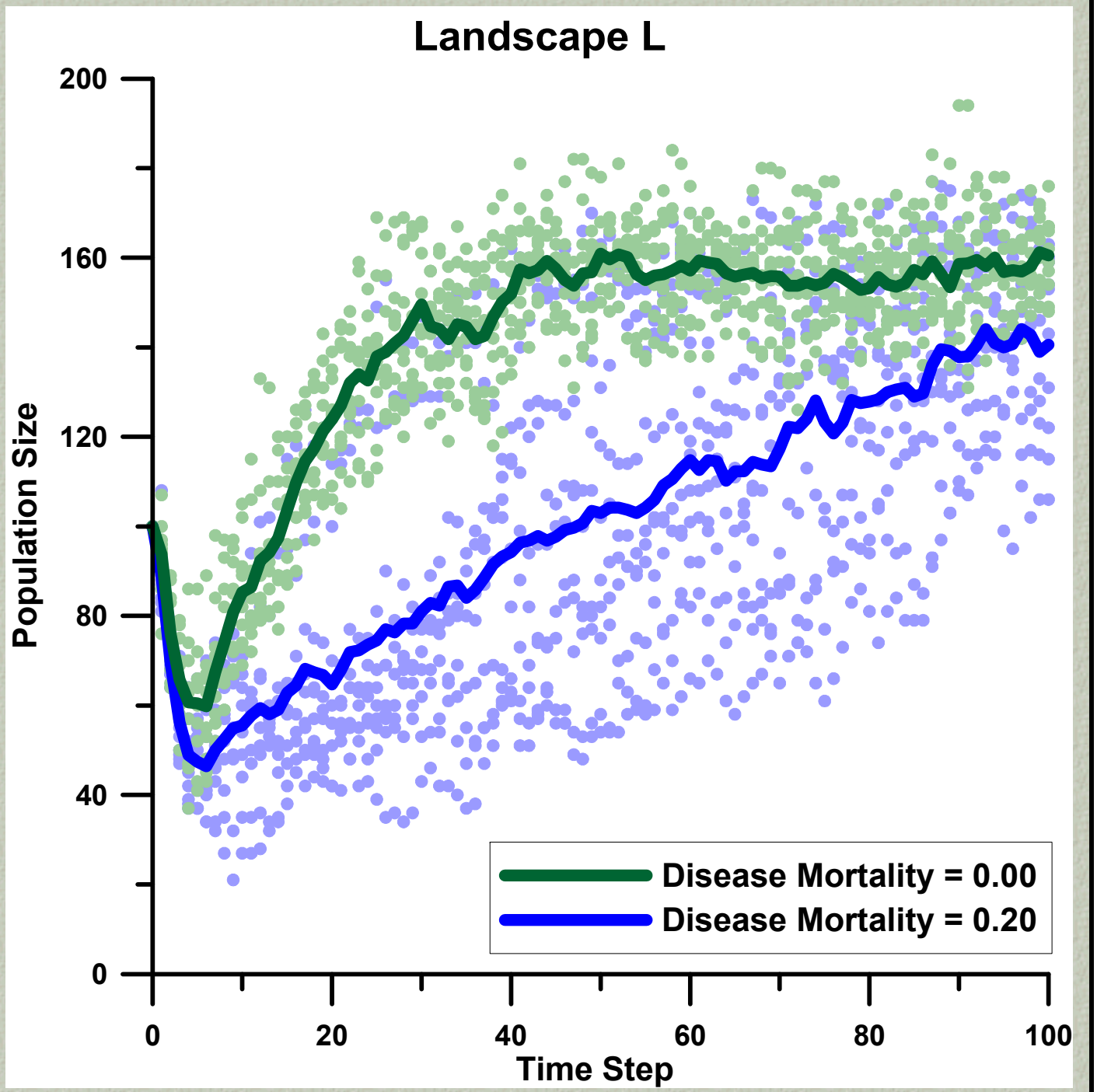


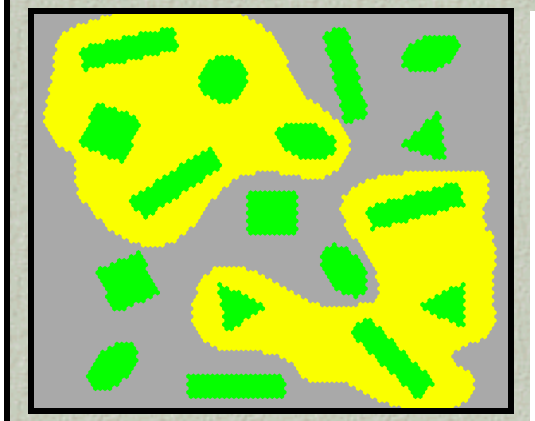

Landscape B
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

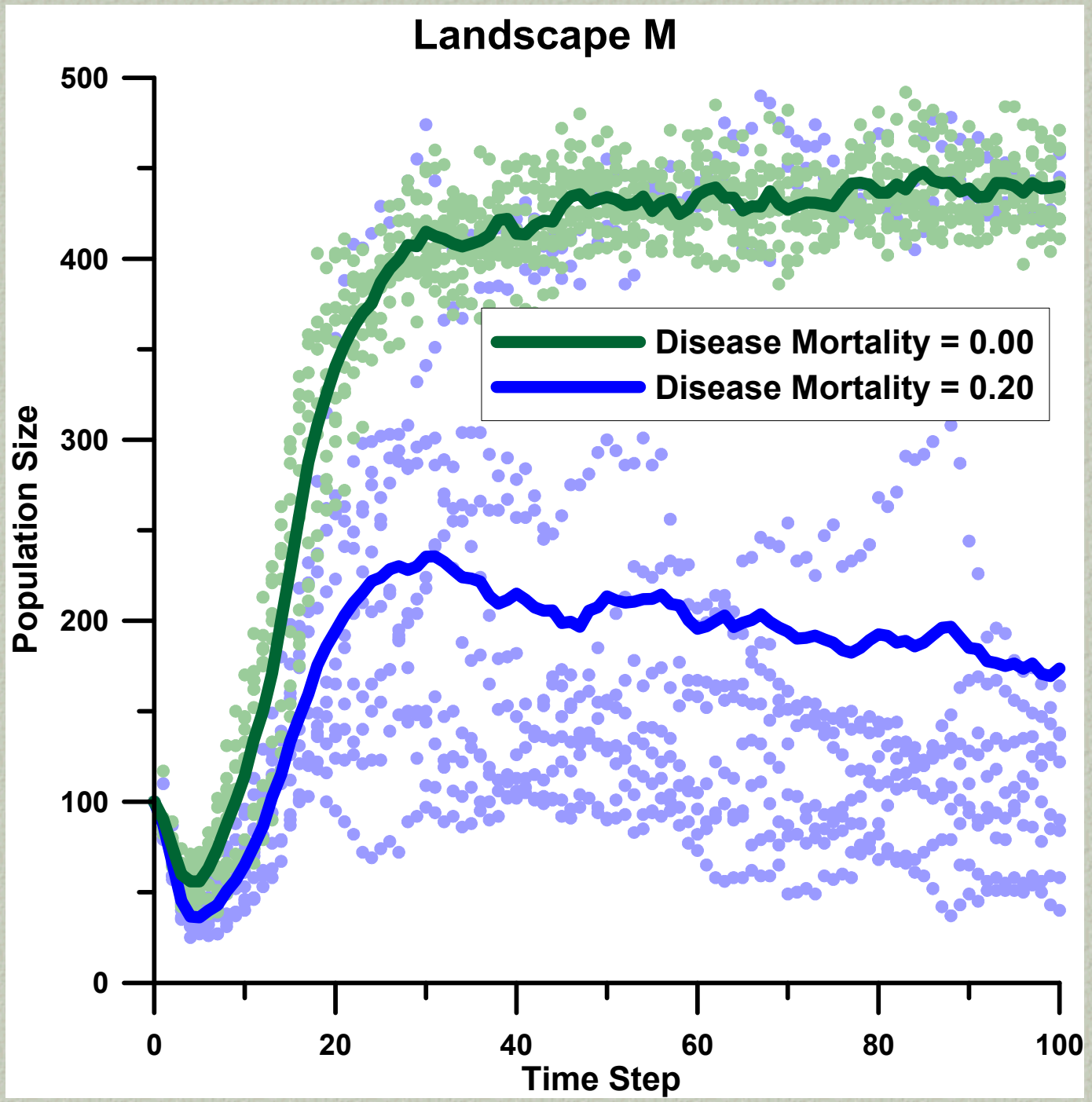


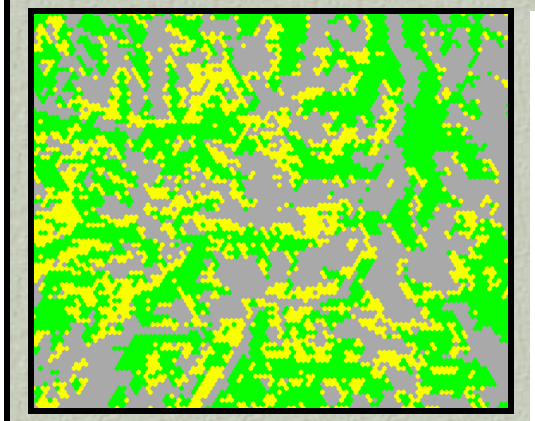

Landscape C
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

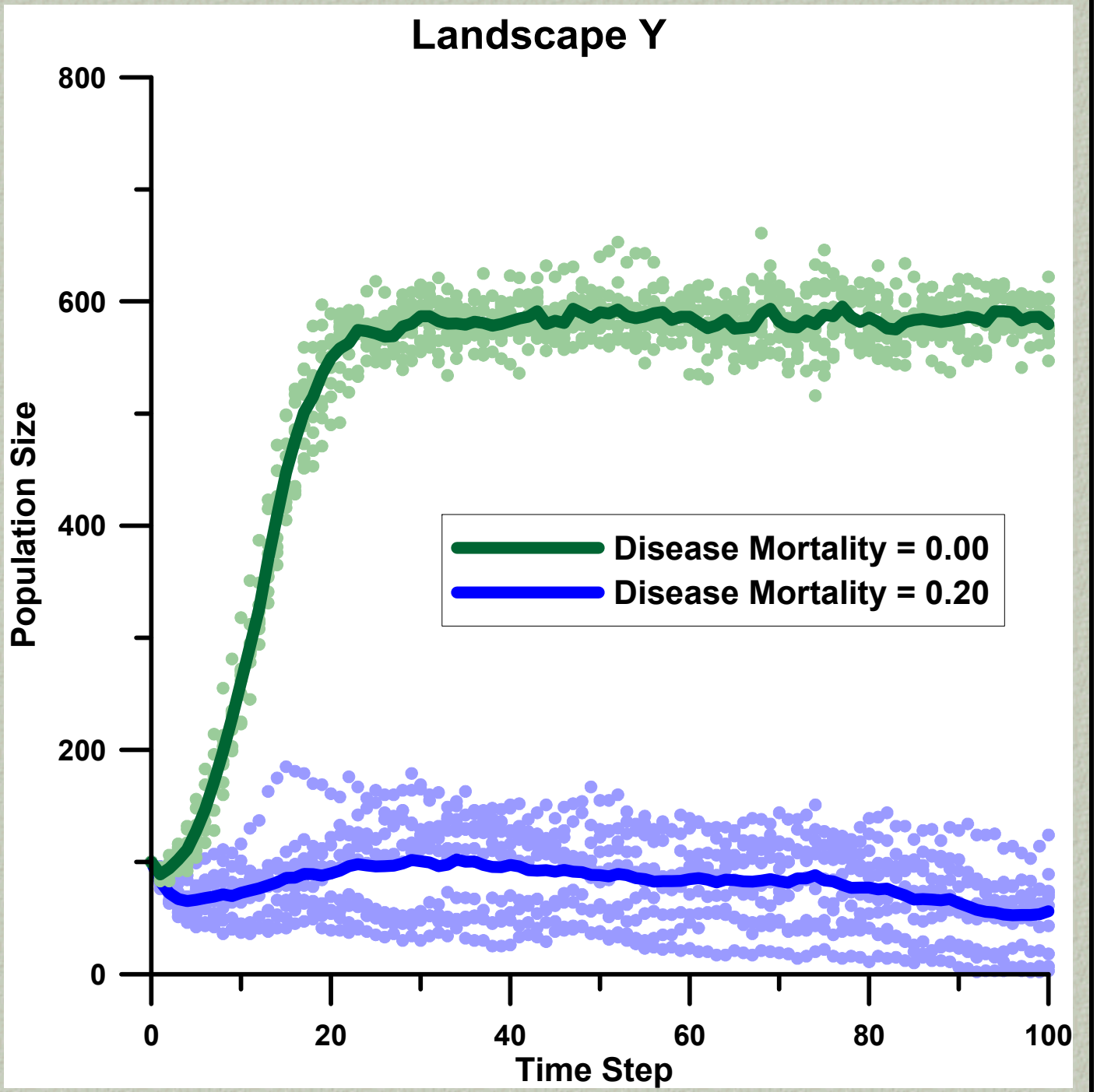


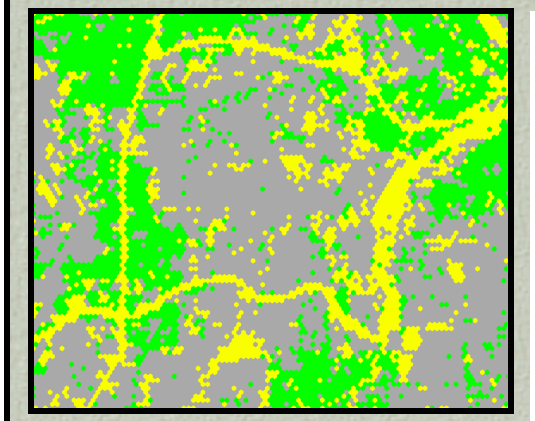

Landscape L
Population Size
200
160
120
80
40
0
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20

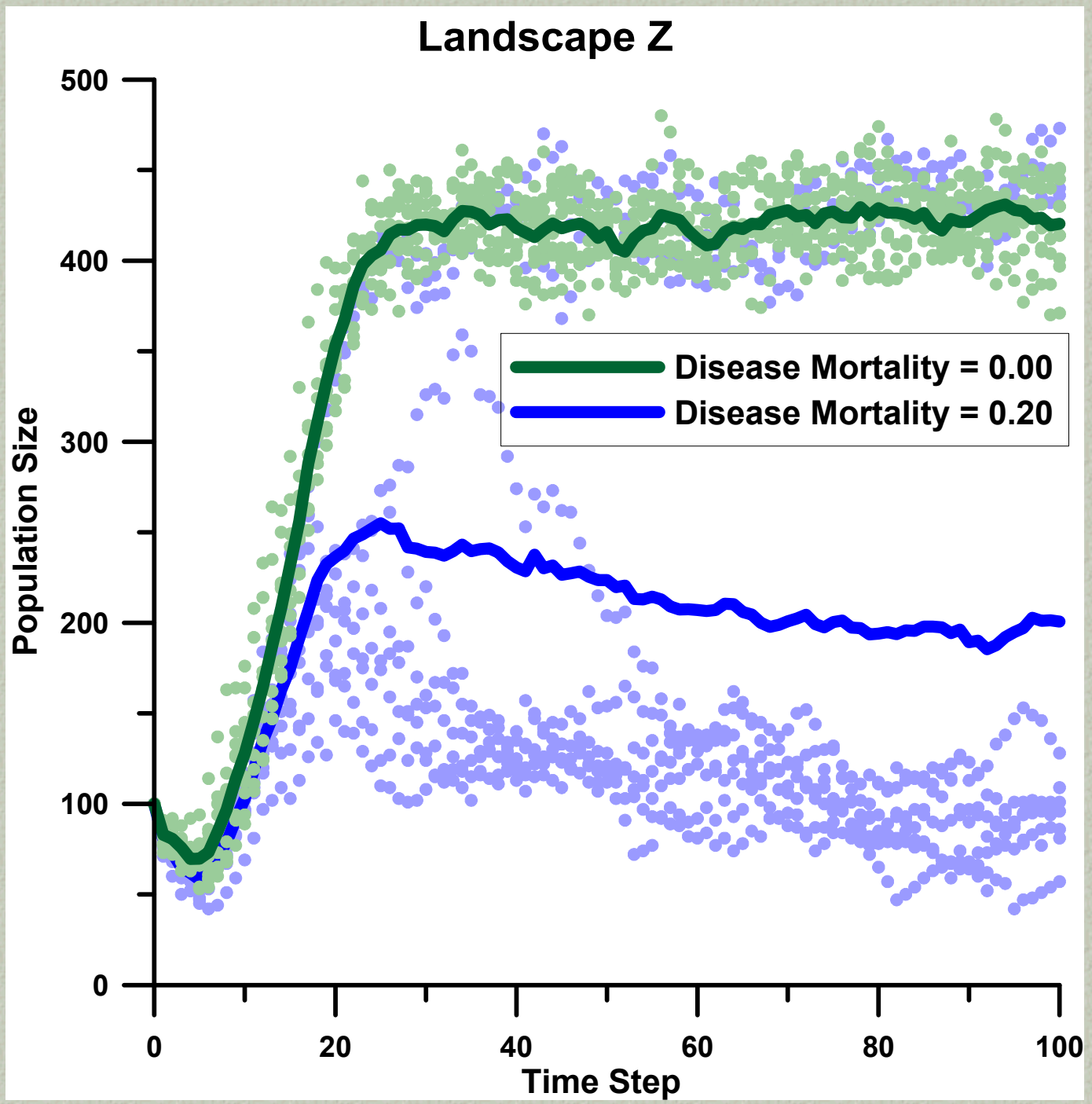



Landscape M
Population Size
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20
0
100
200
300
400
500
0
20
40
60
80
100




Landscape Y
800
600
400
200
0
Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.00
Disease Mortality = 0.20



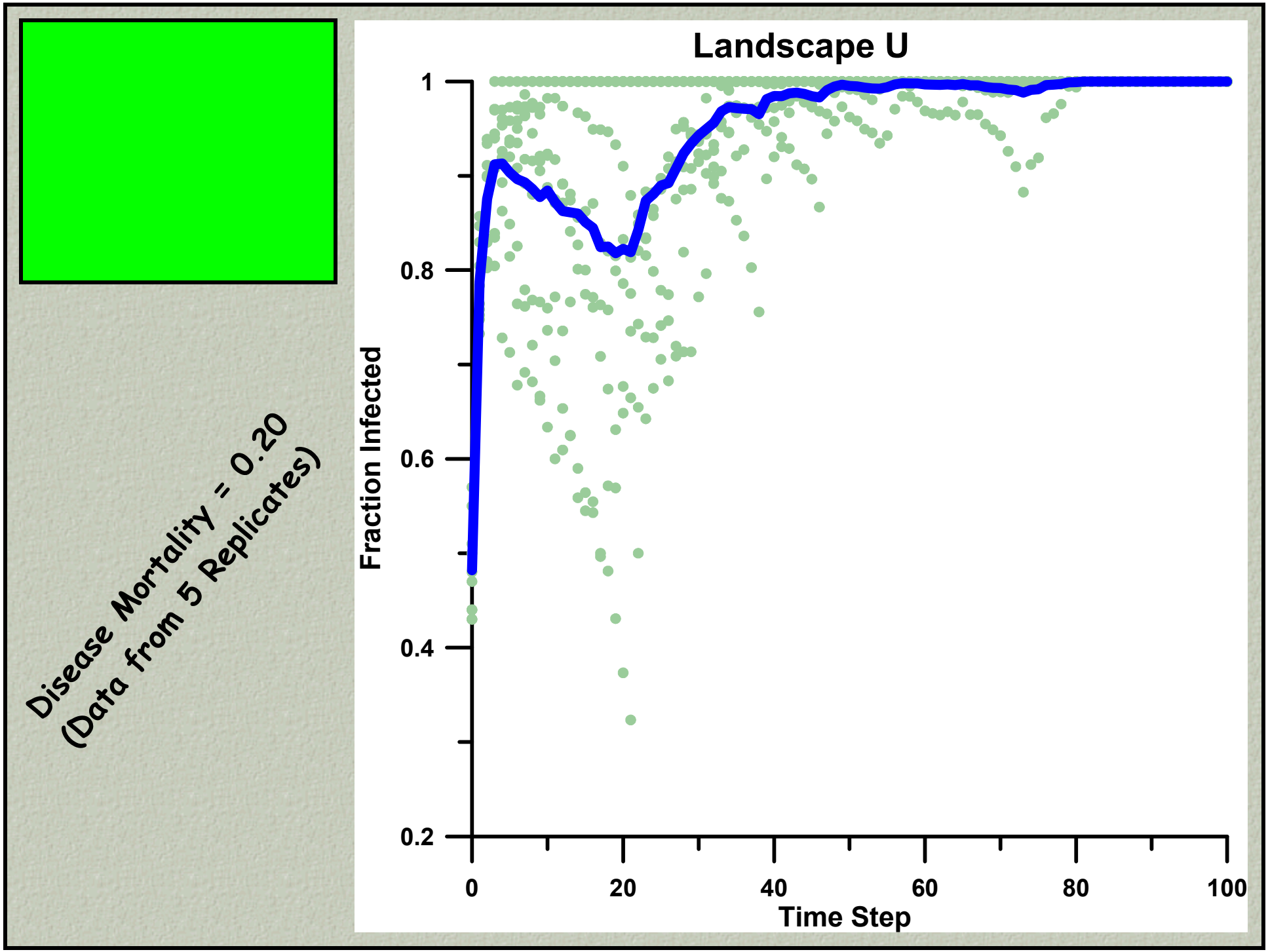

Landscape Z
Population Size
Time Step
0
100
200
300
400
500
0
20
40
60
80
100
Disease Mortality = 0.00
Disease Mortality = 0.20

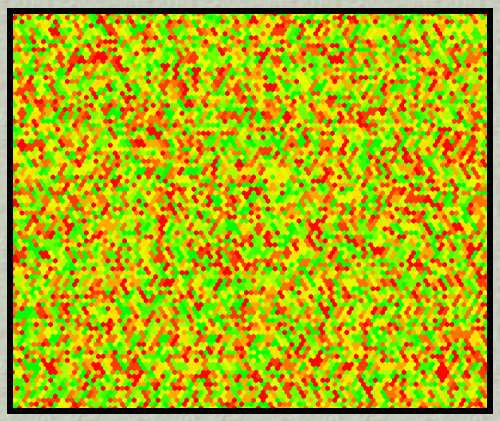
A Series Of Landscape Comparisons

➔ **Percent Infected** ←

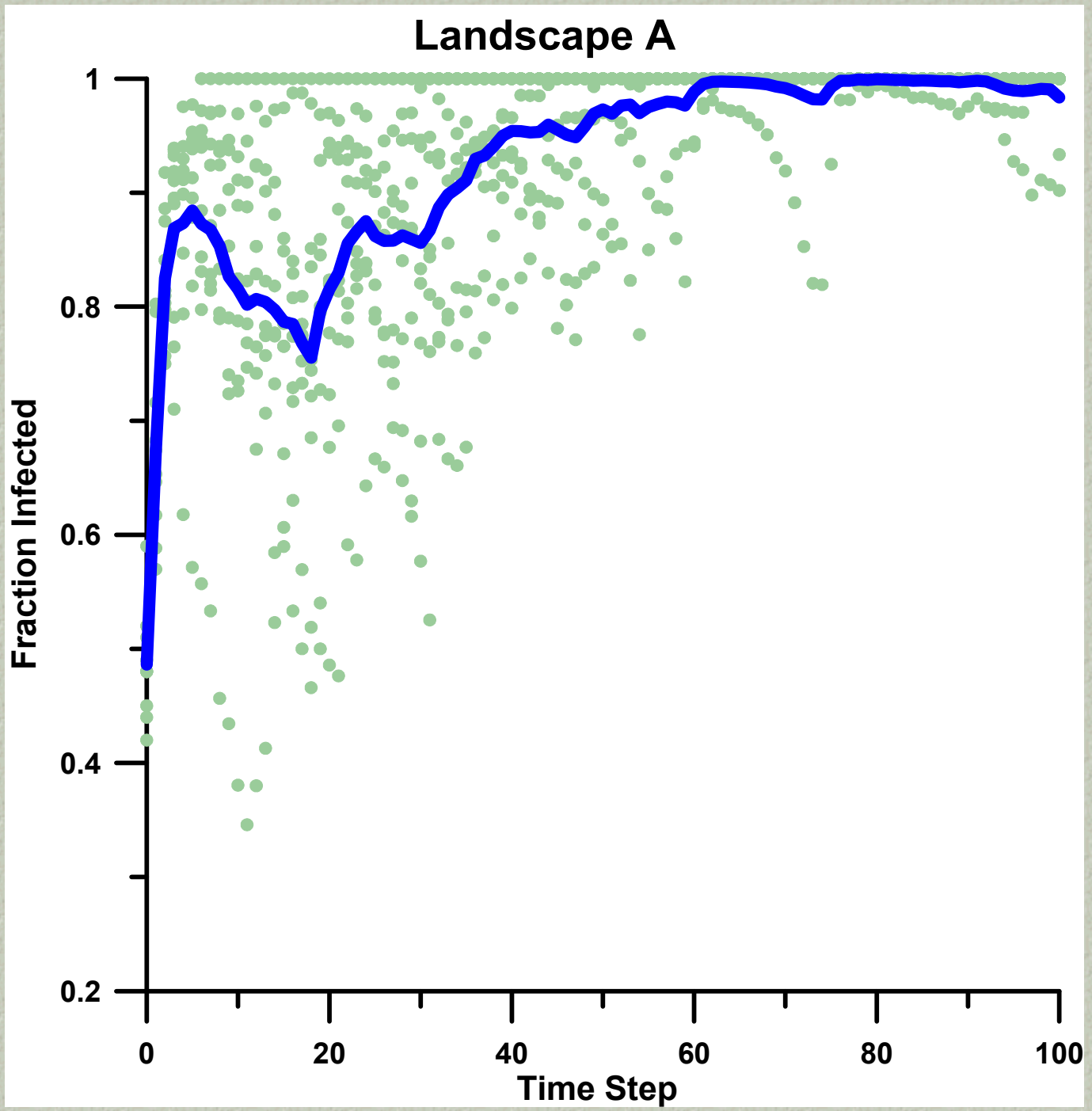
Each simulation consists of 5 replicates
of 100 time steps (years)
Means, and variability are illustrated

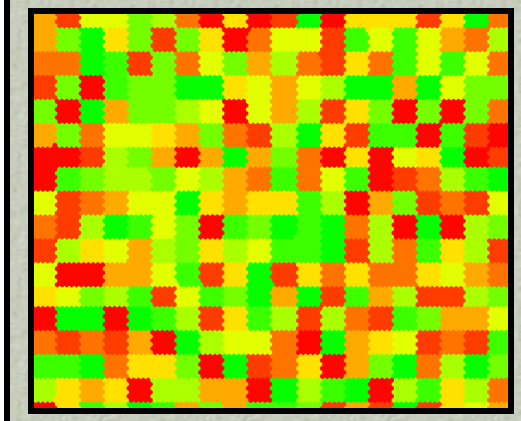
For each landscape, a simulation was run with
Disease mortality = 20% only


Landscape U
Fraction Infected
1
0.8
0.6
0.4
0.2
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)

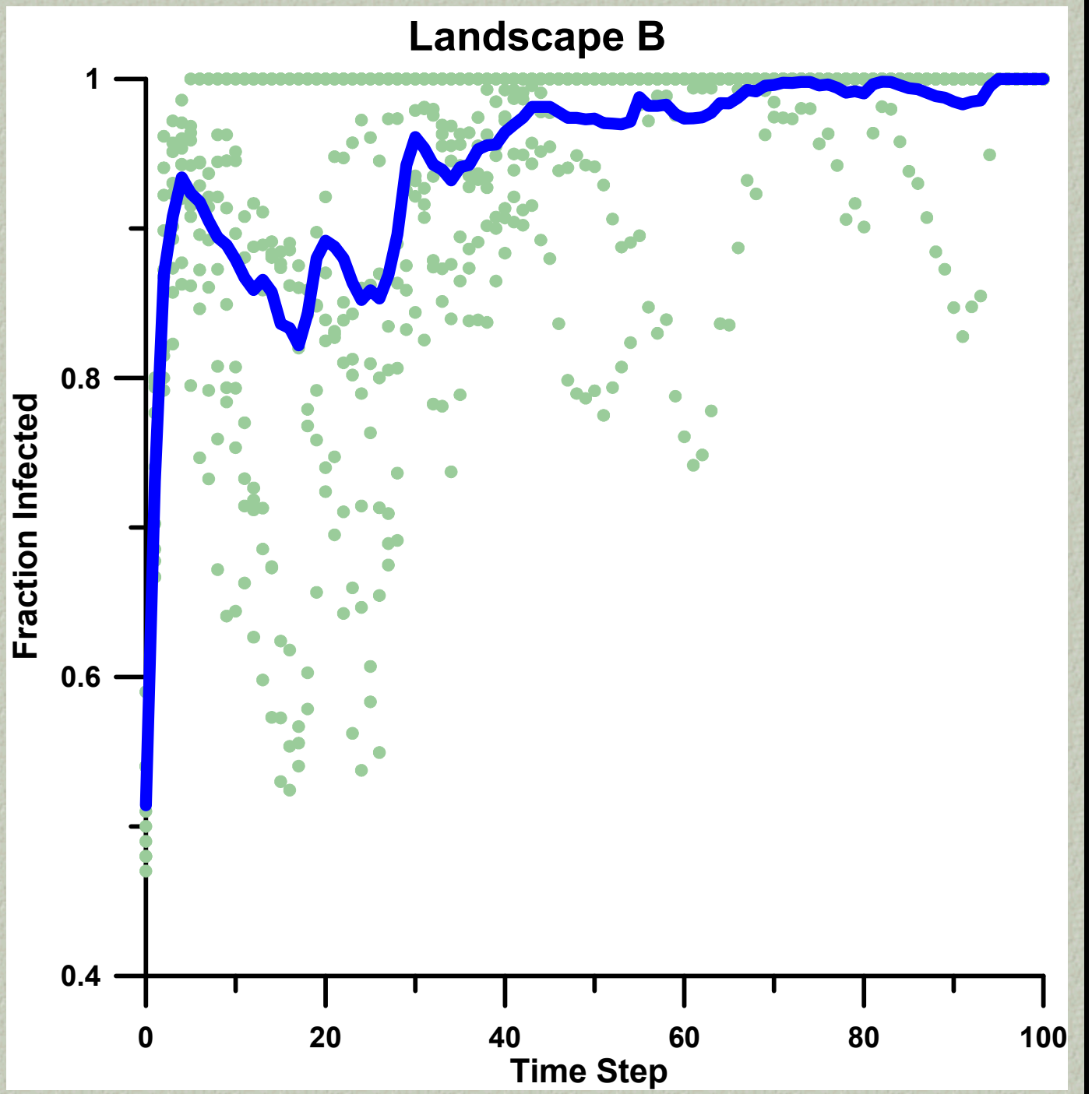


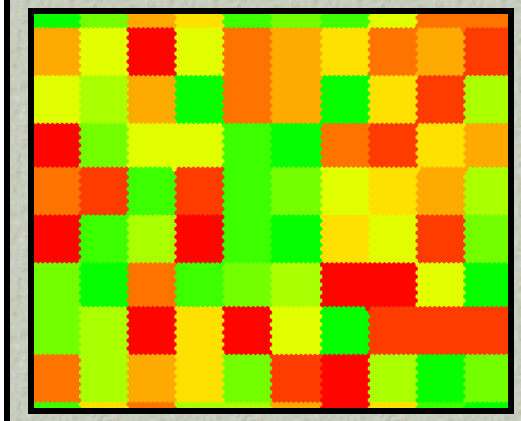
Disease Mortality = 0.20
(Data from 5 Replicates)



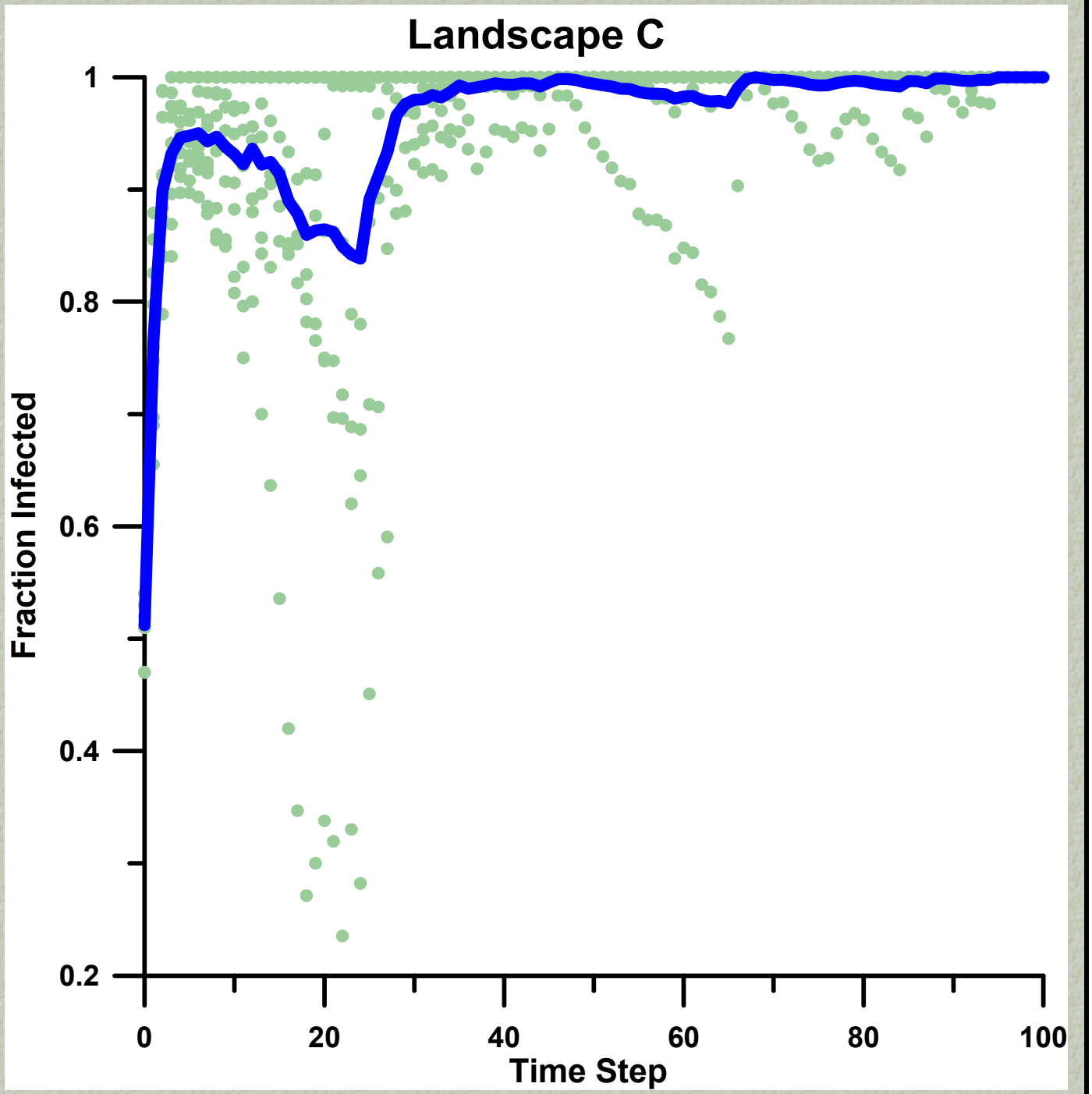


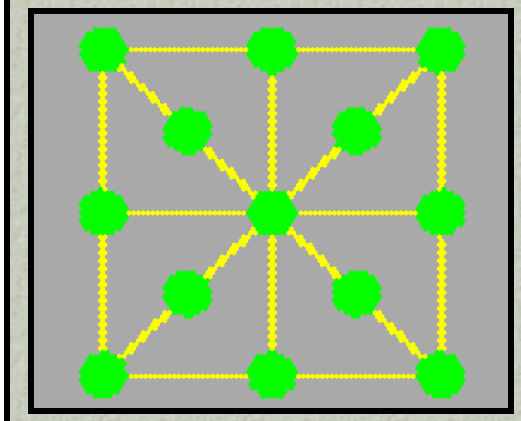
Disease Mortality = 0.20
(Data from 5 Replicates)



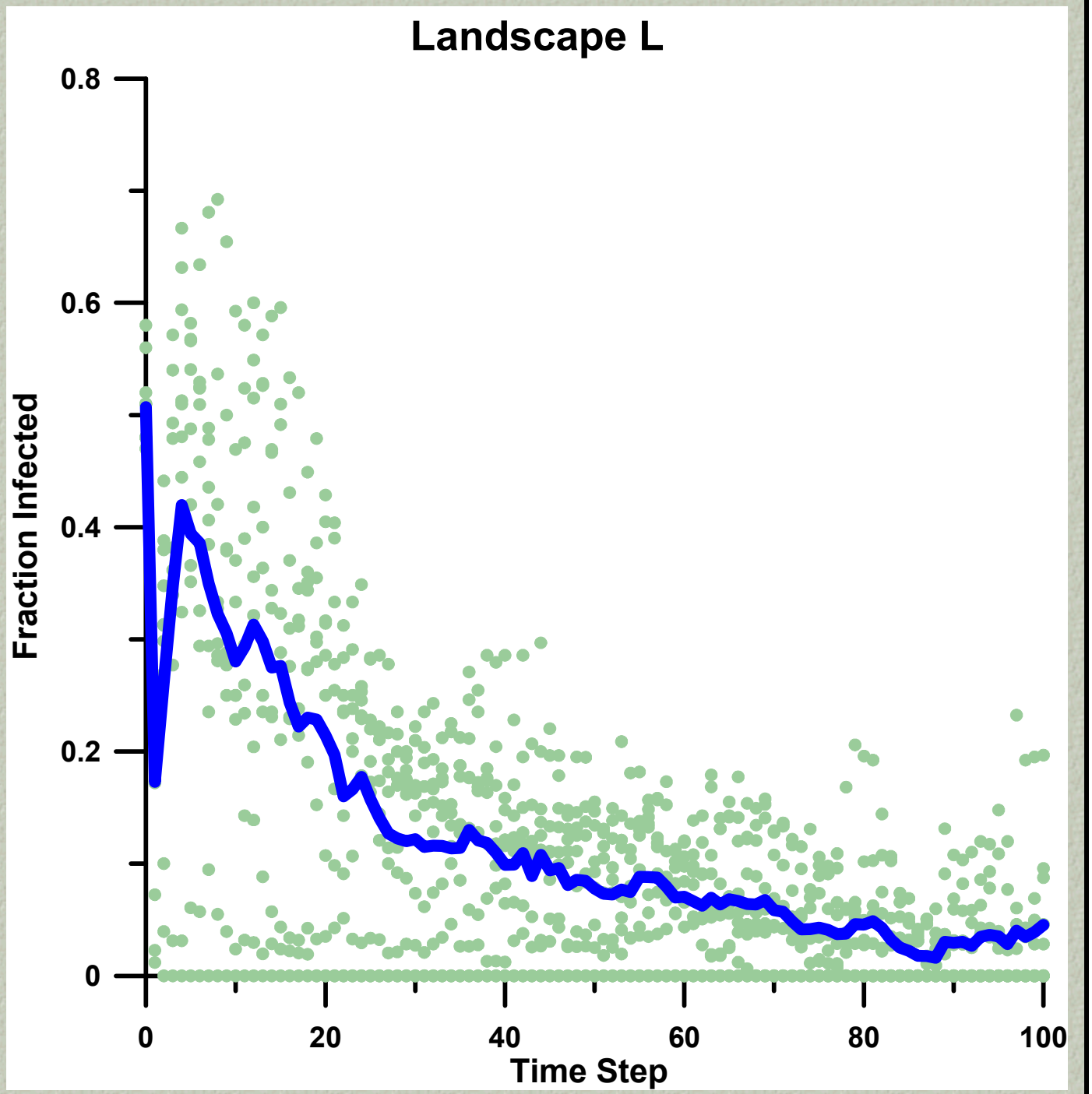


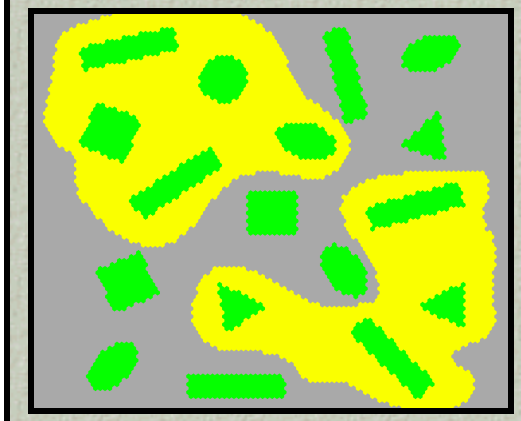
Disease Mortality = 0.20
(Data from 5 Replicates)



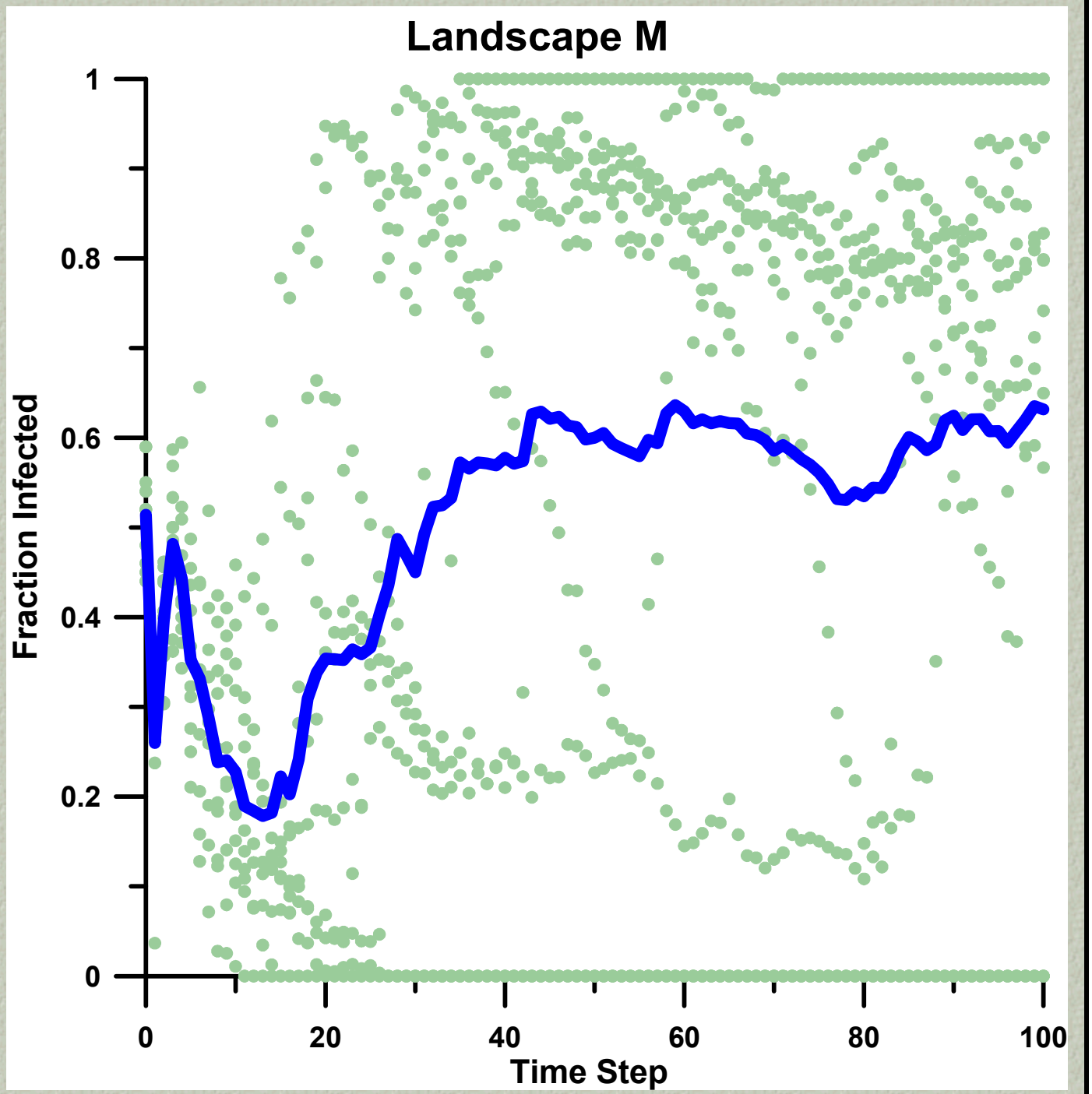


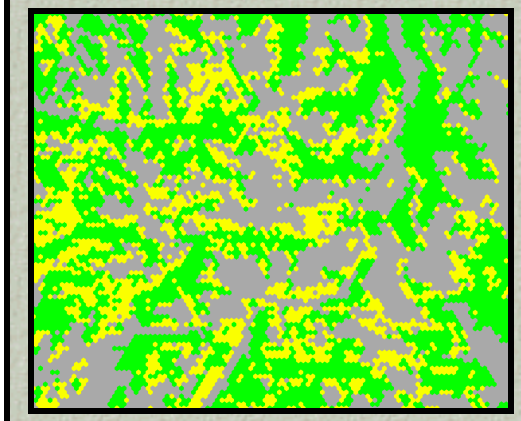
Disease Mortality = 0.20
(Data from 5 Replicates)



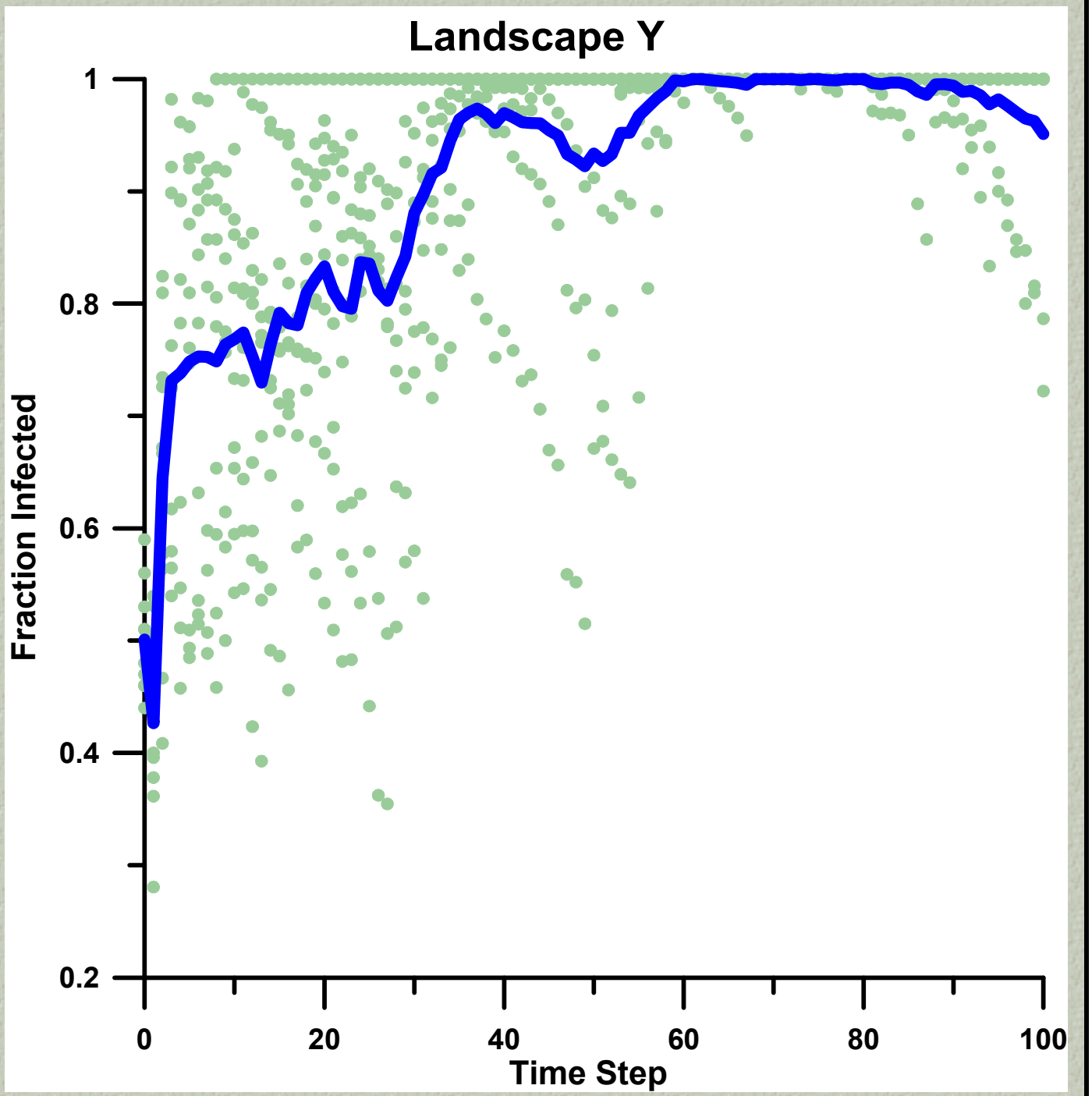


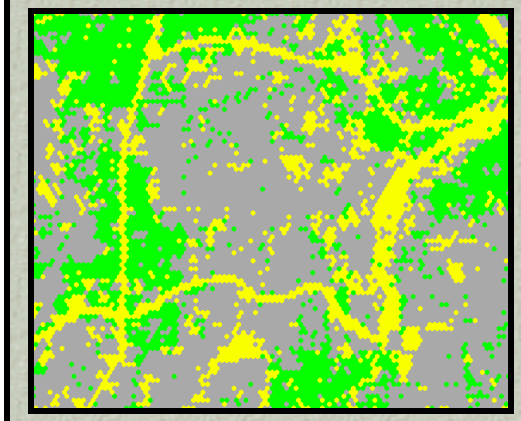
Disease Mortality = 0.20
(Data from 5 Replicates)



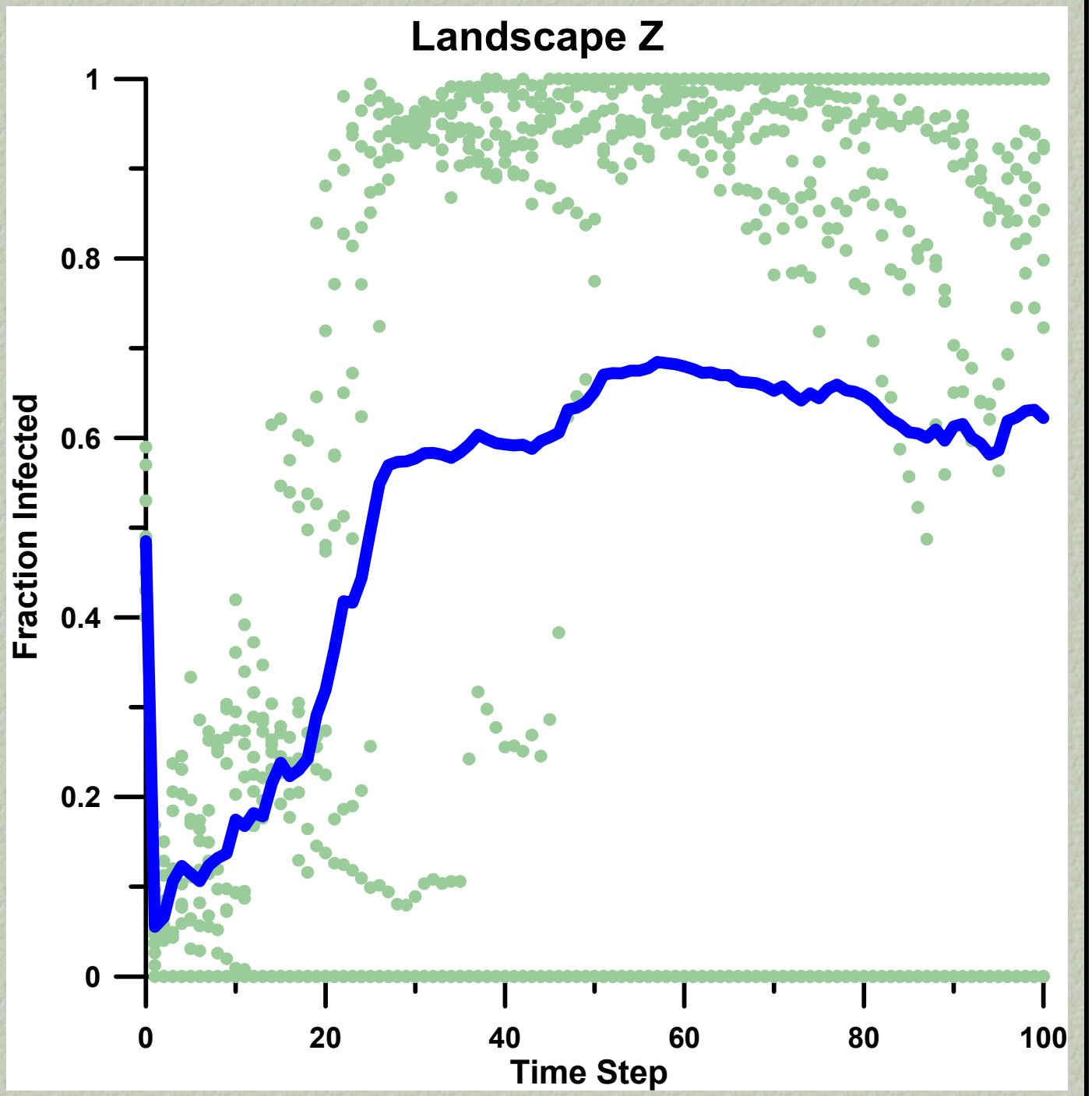


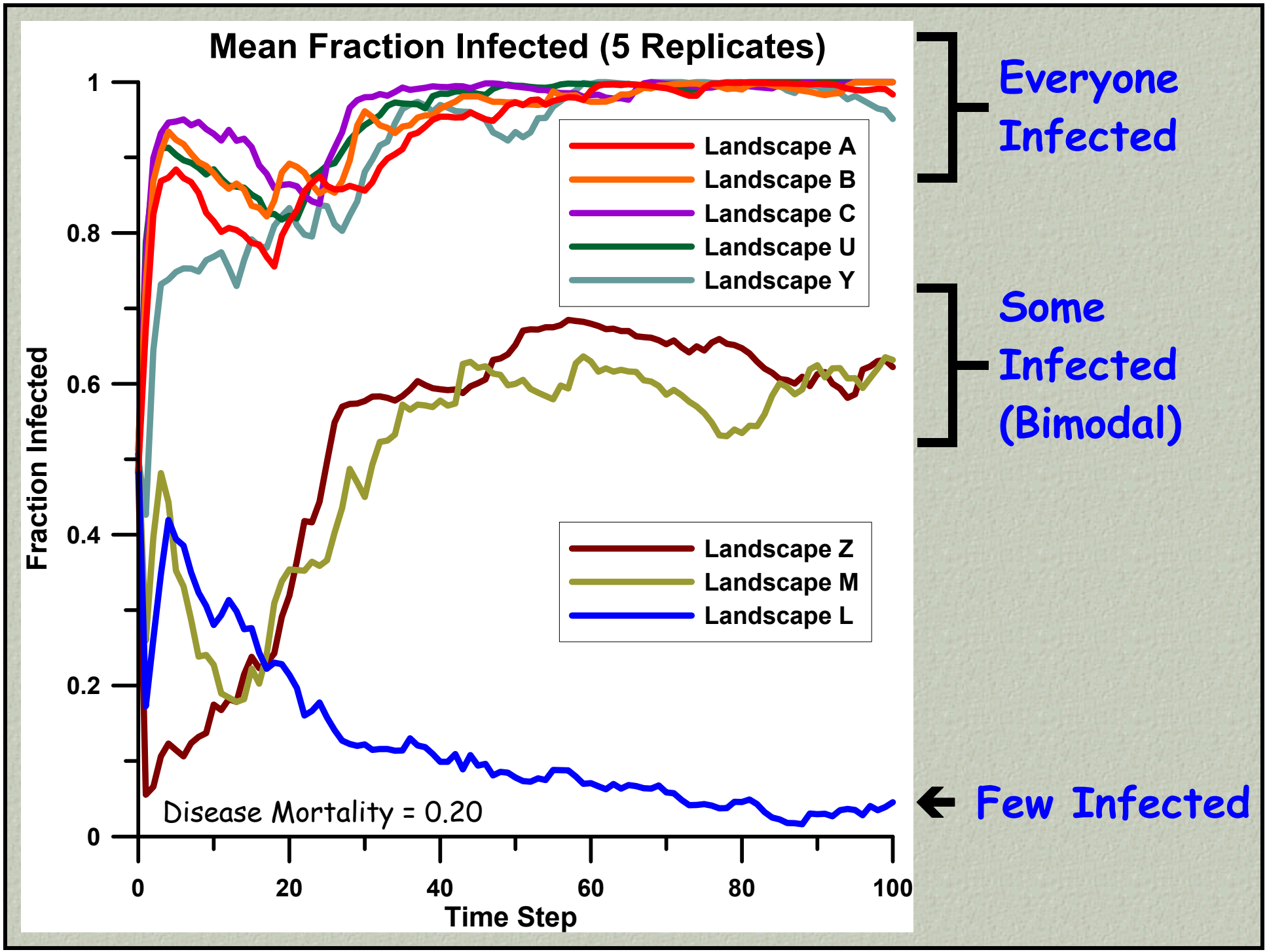
Disease Mortality = 0.20
(Data from 5 Replicates)





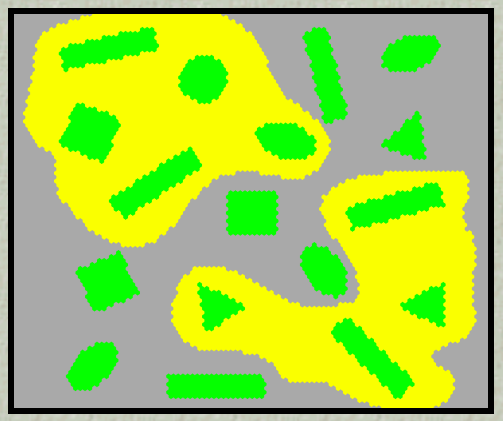
Disease Mortality = 0.20
(Data from 5 Replicates)

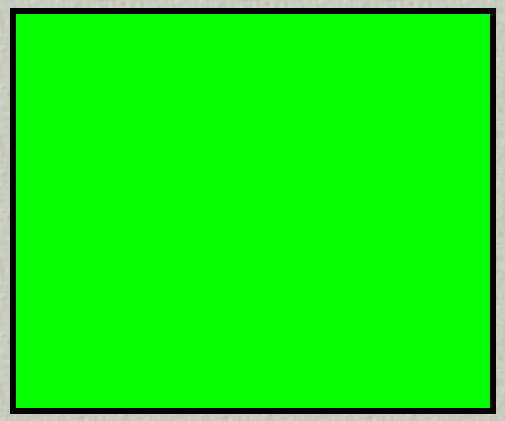


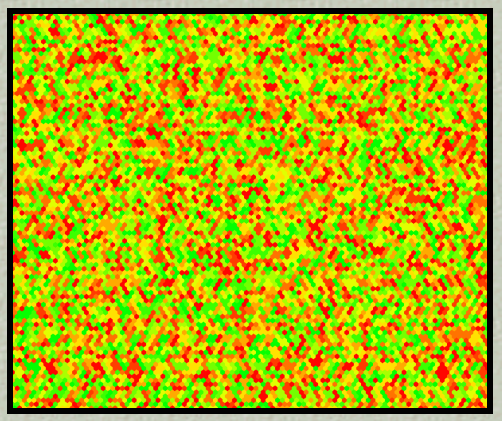

Mean Fraction Infected (5 Replicates)
Fraction Infected
1
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Time Step
Landscape A
Landscape B
Landscape C
Landscape U
Landscape Y
Landscape Z
Landscape M
Landscape L
Disease Mortality = 0.20
Everyone Infected
Some Infected (Bimodal)
Few Infected

Bimodal

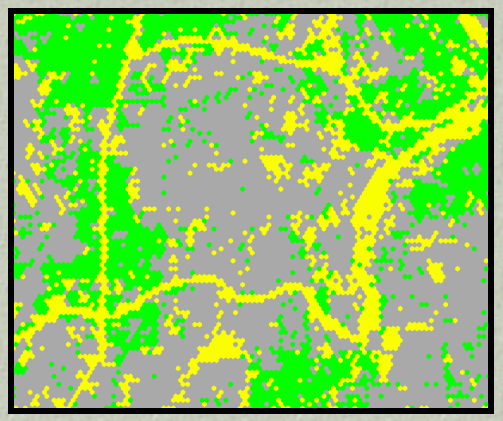
Everyone Infected

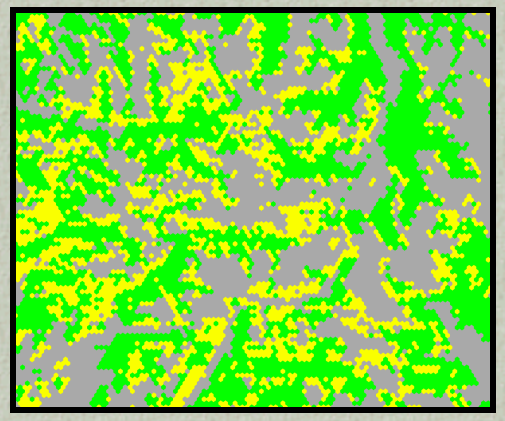


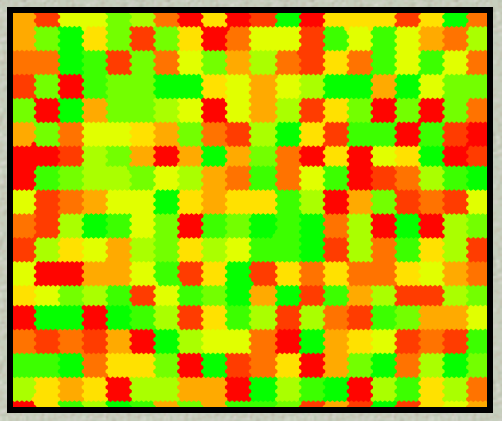


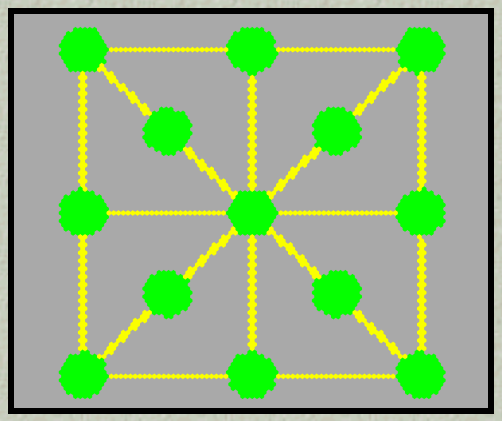


Disease Mortality = 20%

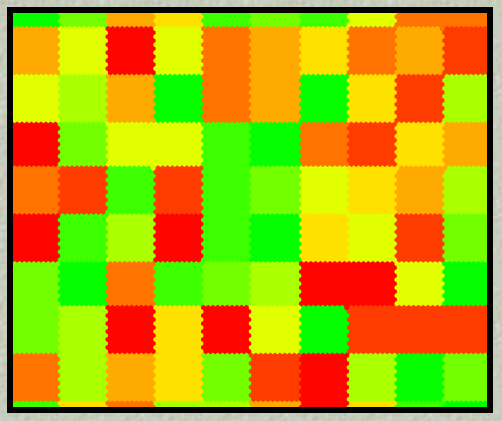








Few Infected



Quick Recap

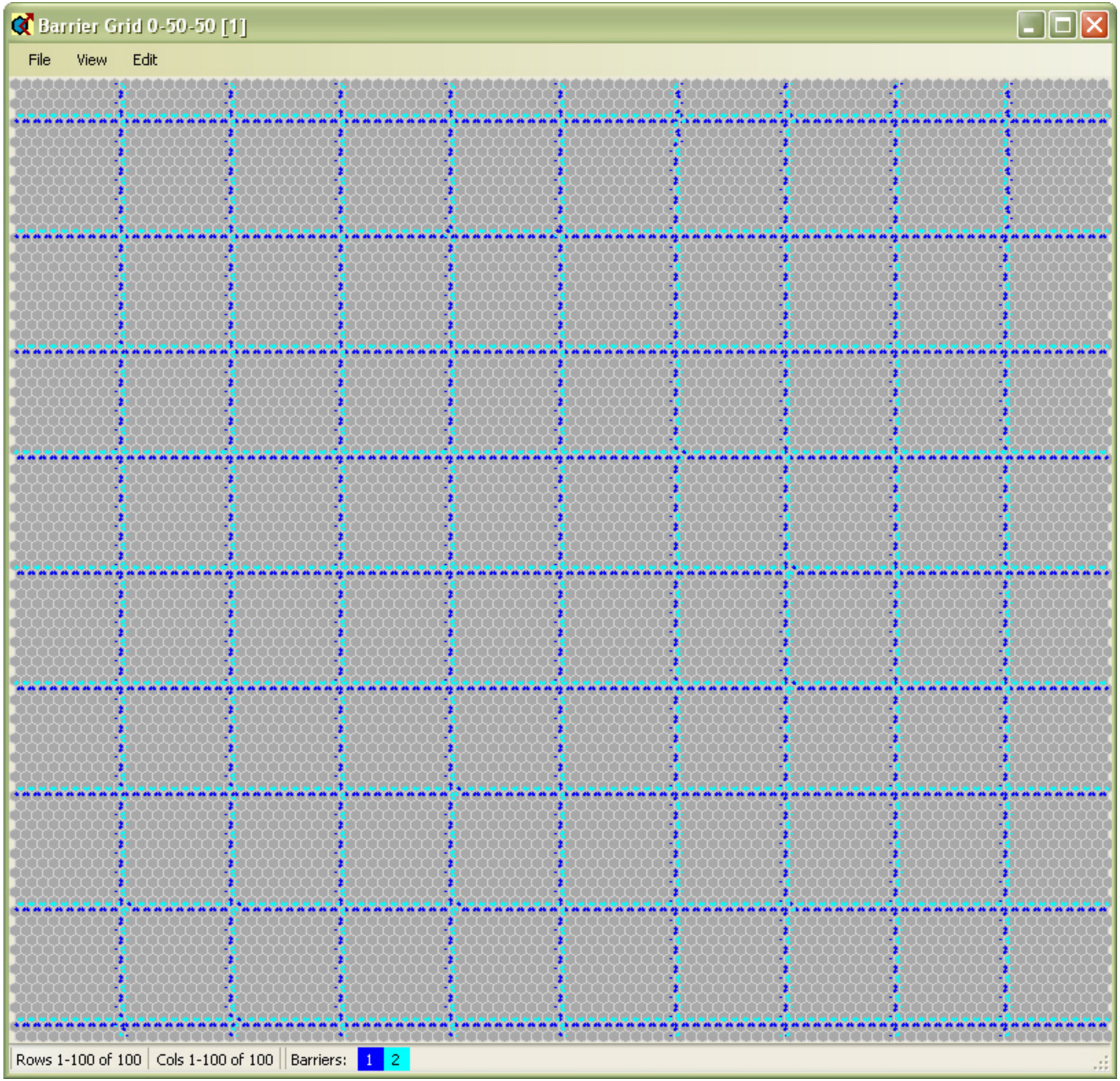
We have looked at the impact of disease on population dynamics in 8 model landscapes

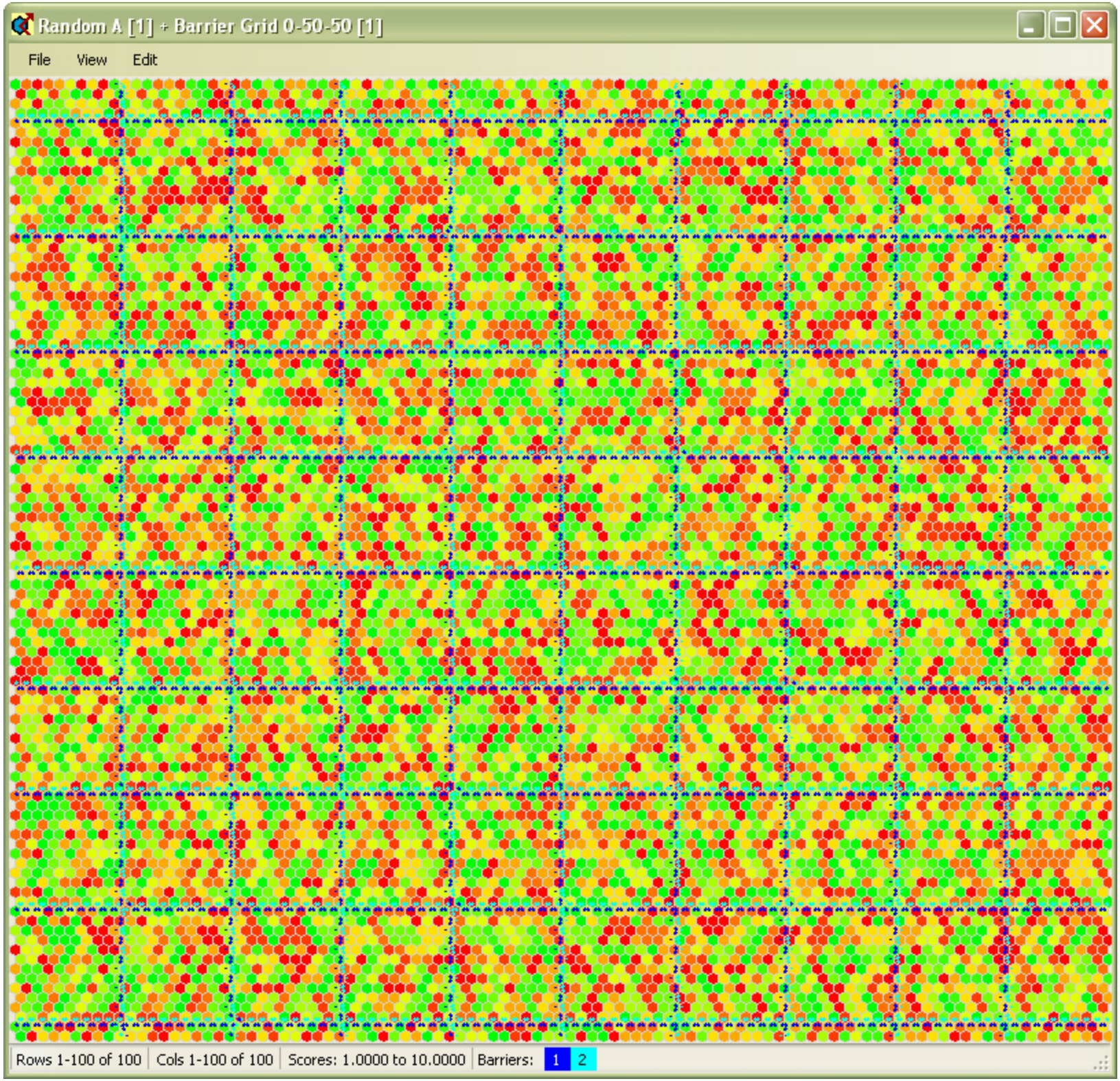
- Landscapes L, M, and Z seemed to be outliers
- Disease had minimal impact on L's pop-size
- Disease had limited impact on M & Z's pop-size
- This was mirrored in the %-infected results

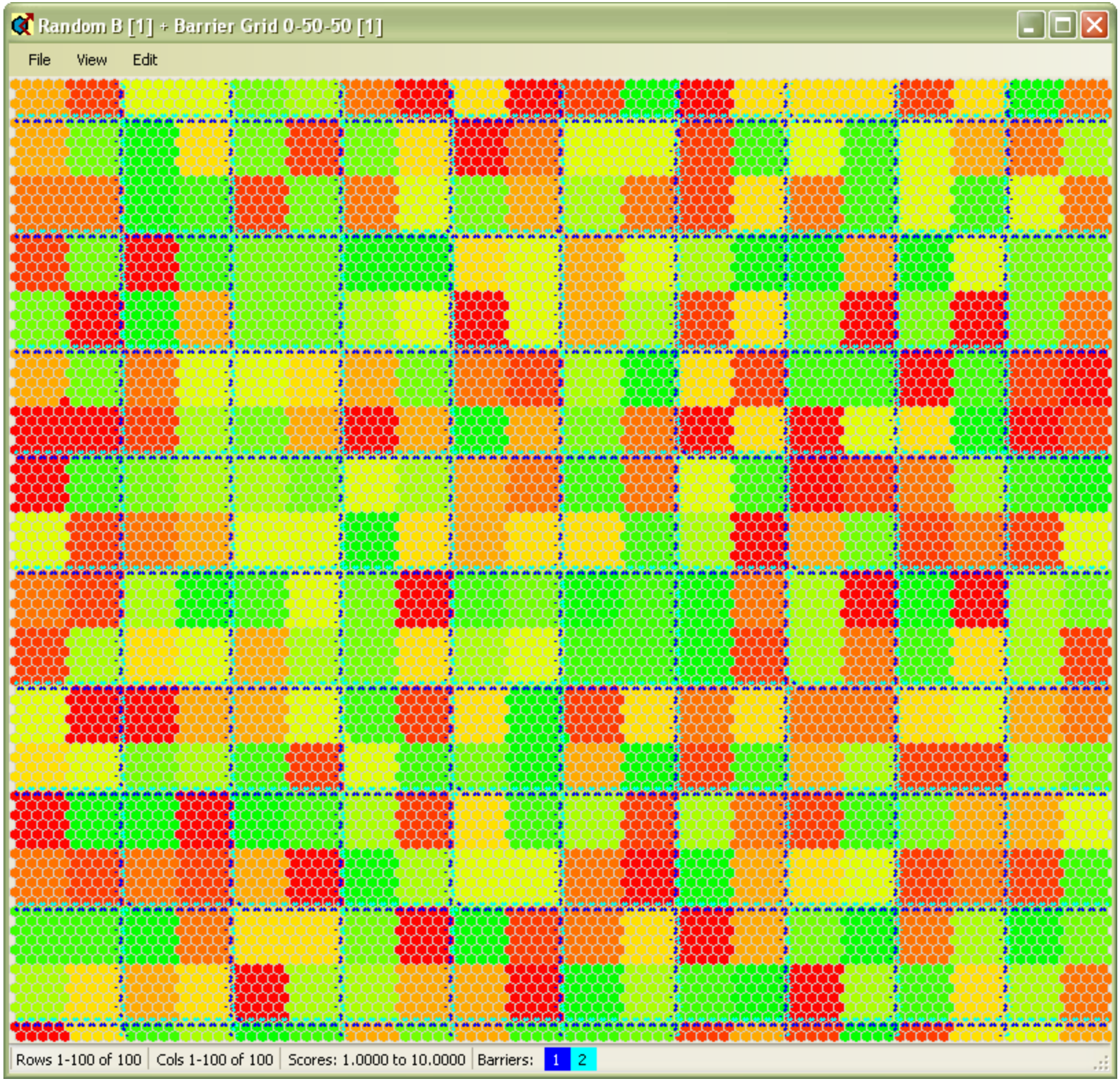
Some Experiments With Connectivity

First -- add a reflecting barrier grid to landscapes *A*, B, and *C*

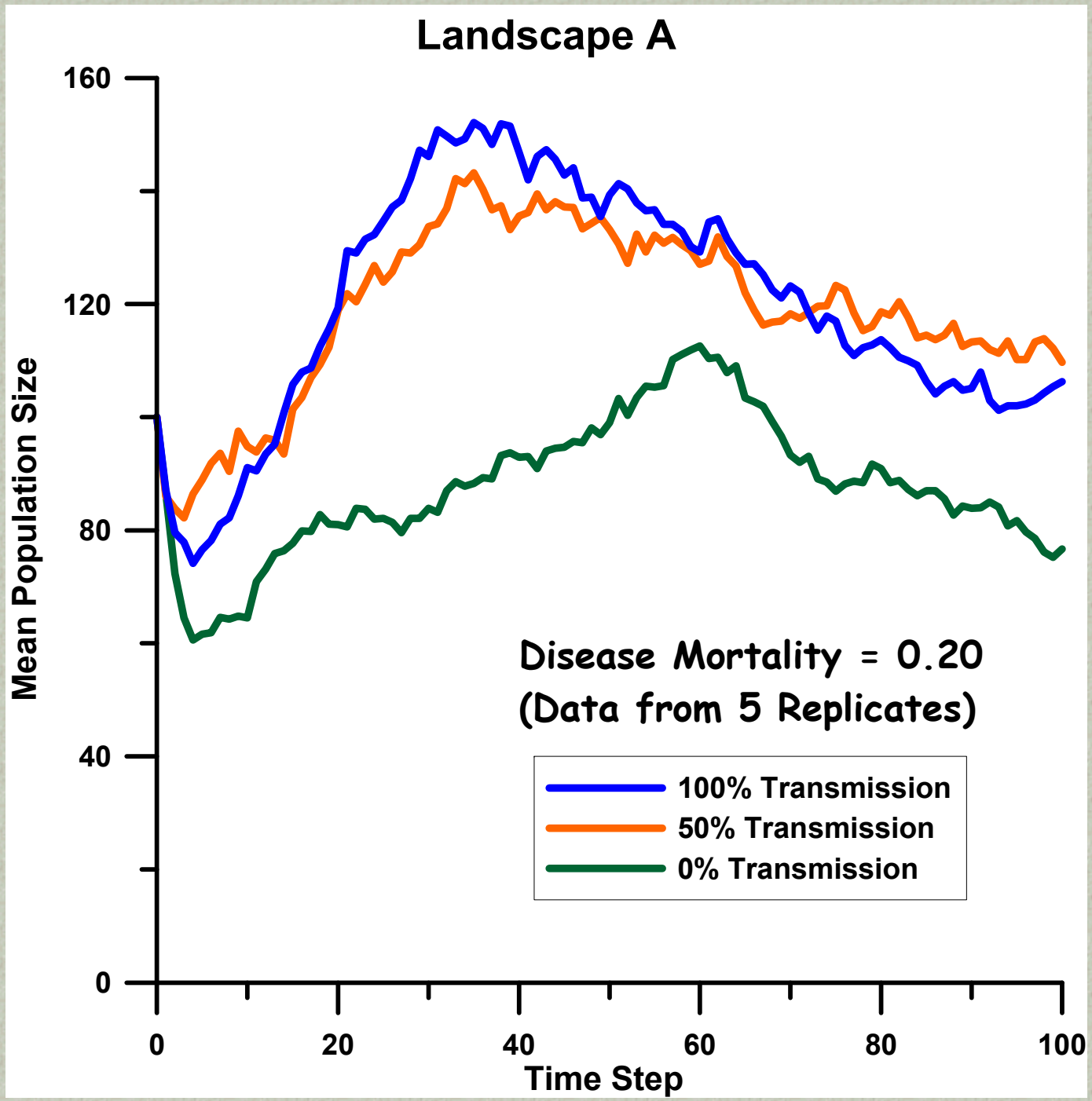
Second -- add an absorbing barrier region to landscape Z

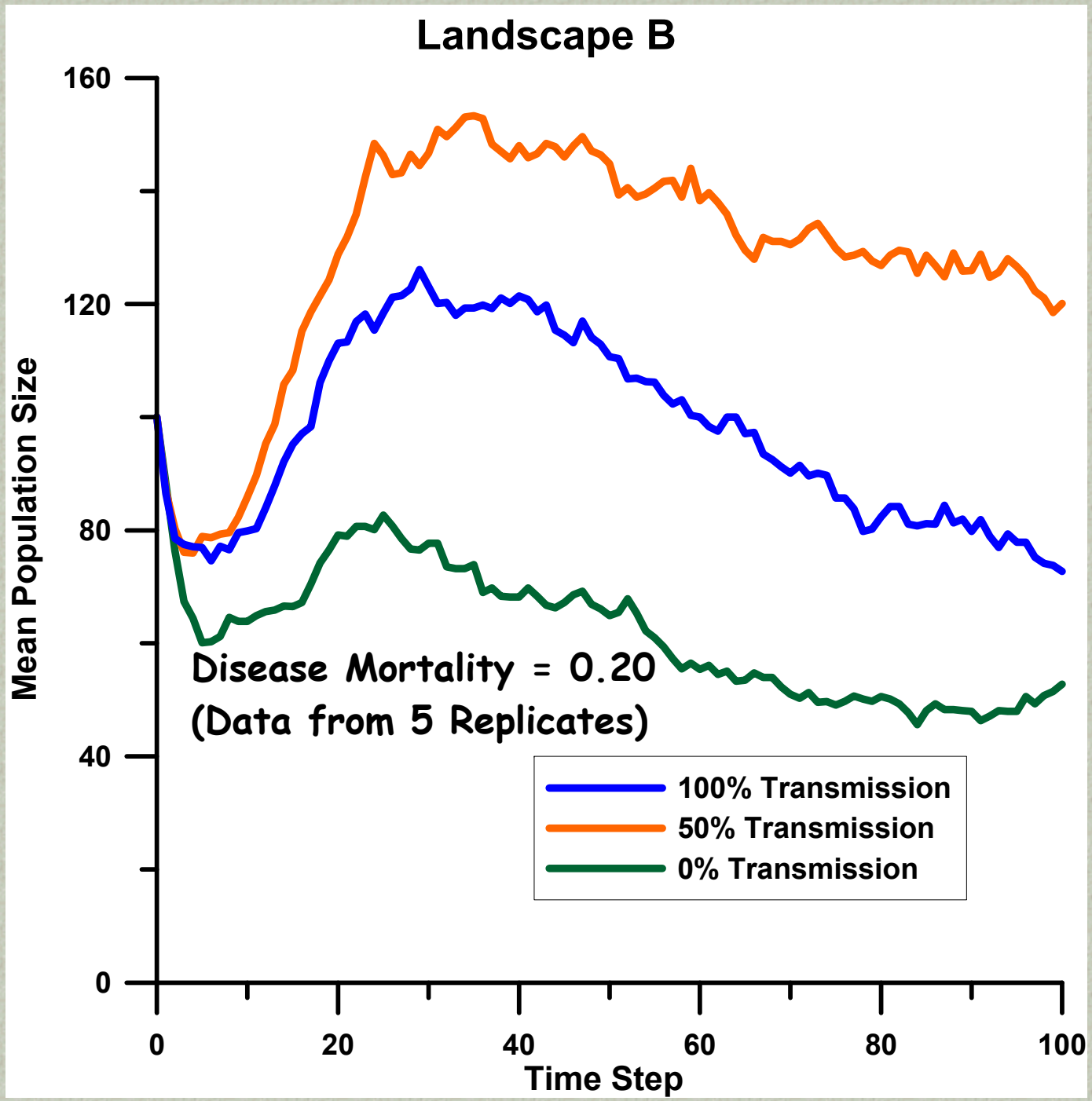

Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Barriers:
1
2

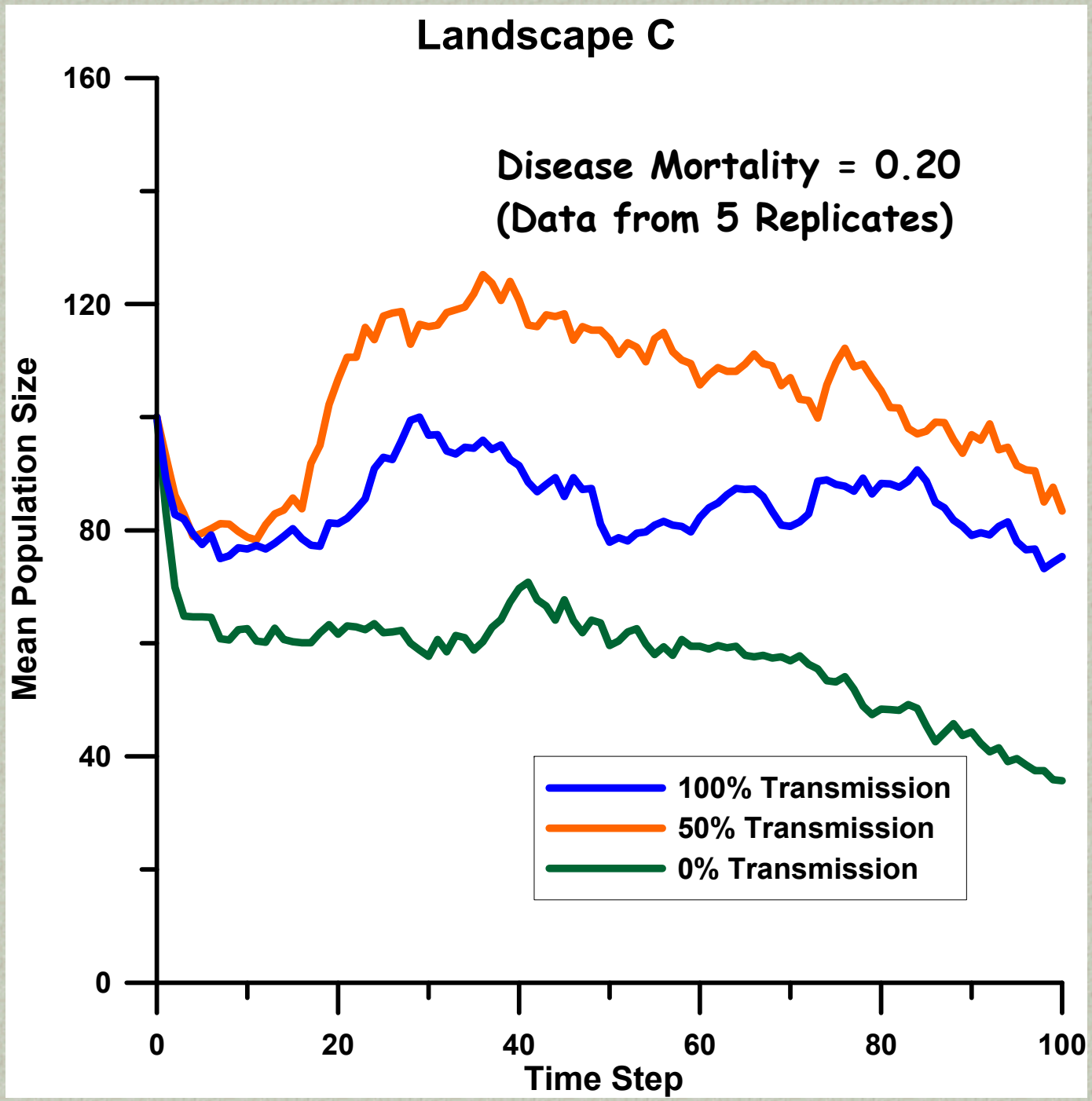

Random A [1] + Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Scores: 1.0000 to 10.0000
Barriers:
1
2

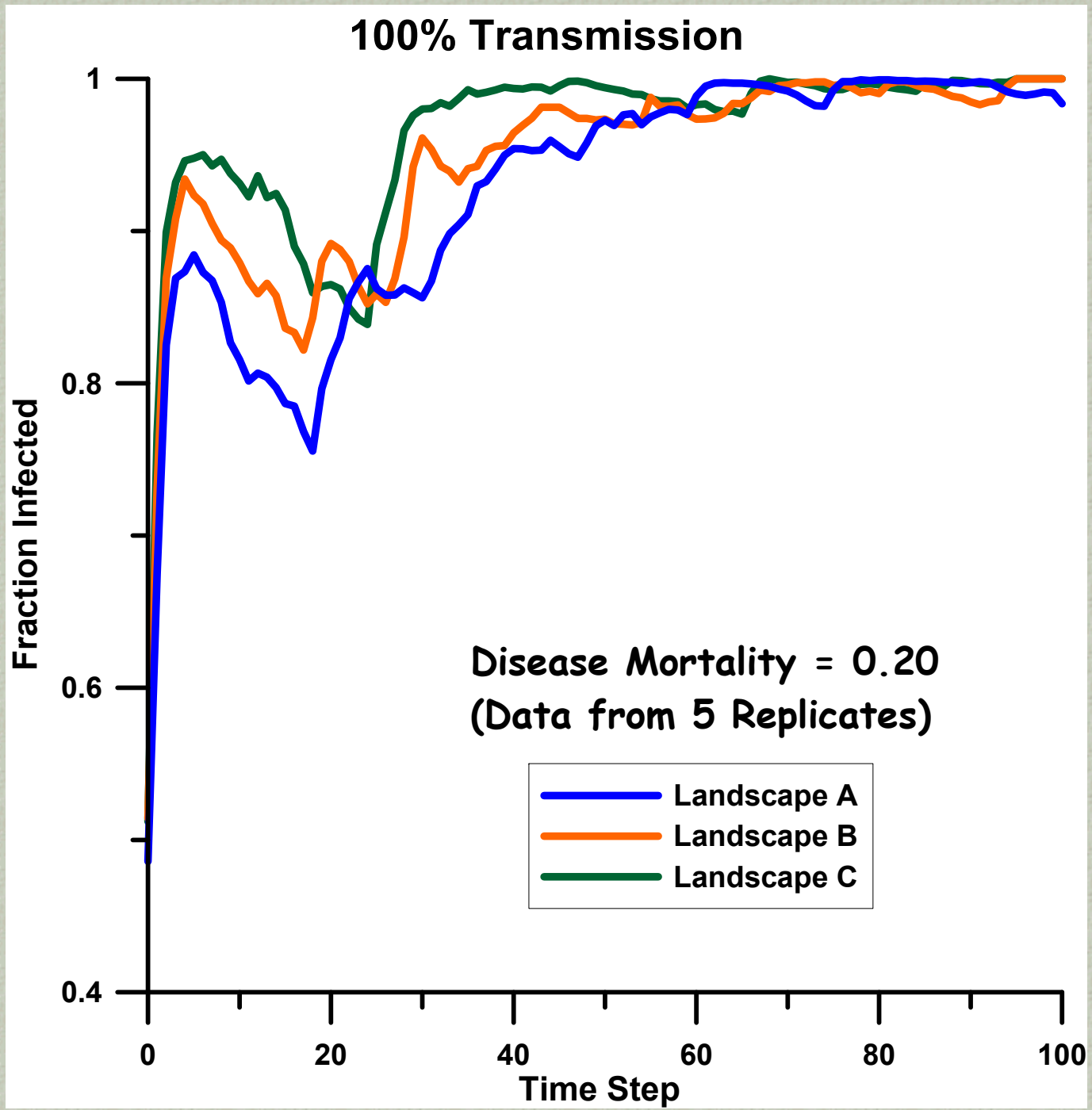

Random B [1] + Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Scores: 1.0000 to 10.0000
Barriers:
1
2

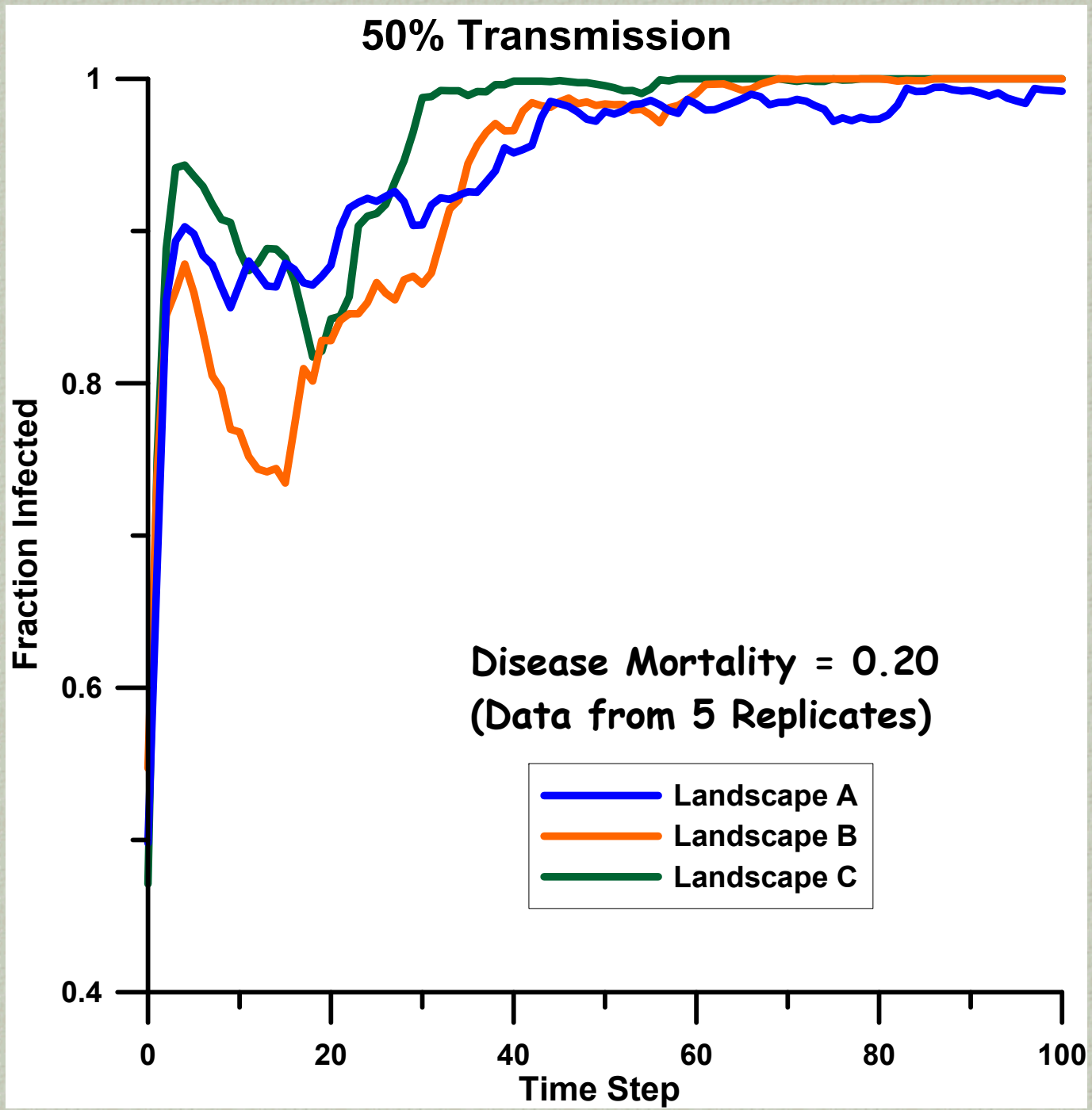
Random C [1] + Barrier Grid 0-50-50 [1]
File
View
Edit
Rows 1-100 of 100
Cols 1-100 of 100
Scores: 1.0000 to 10.0000
Barriers:
1
2

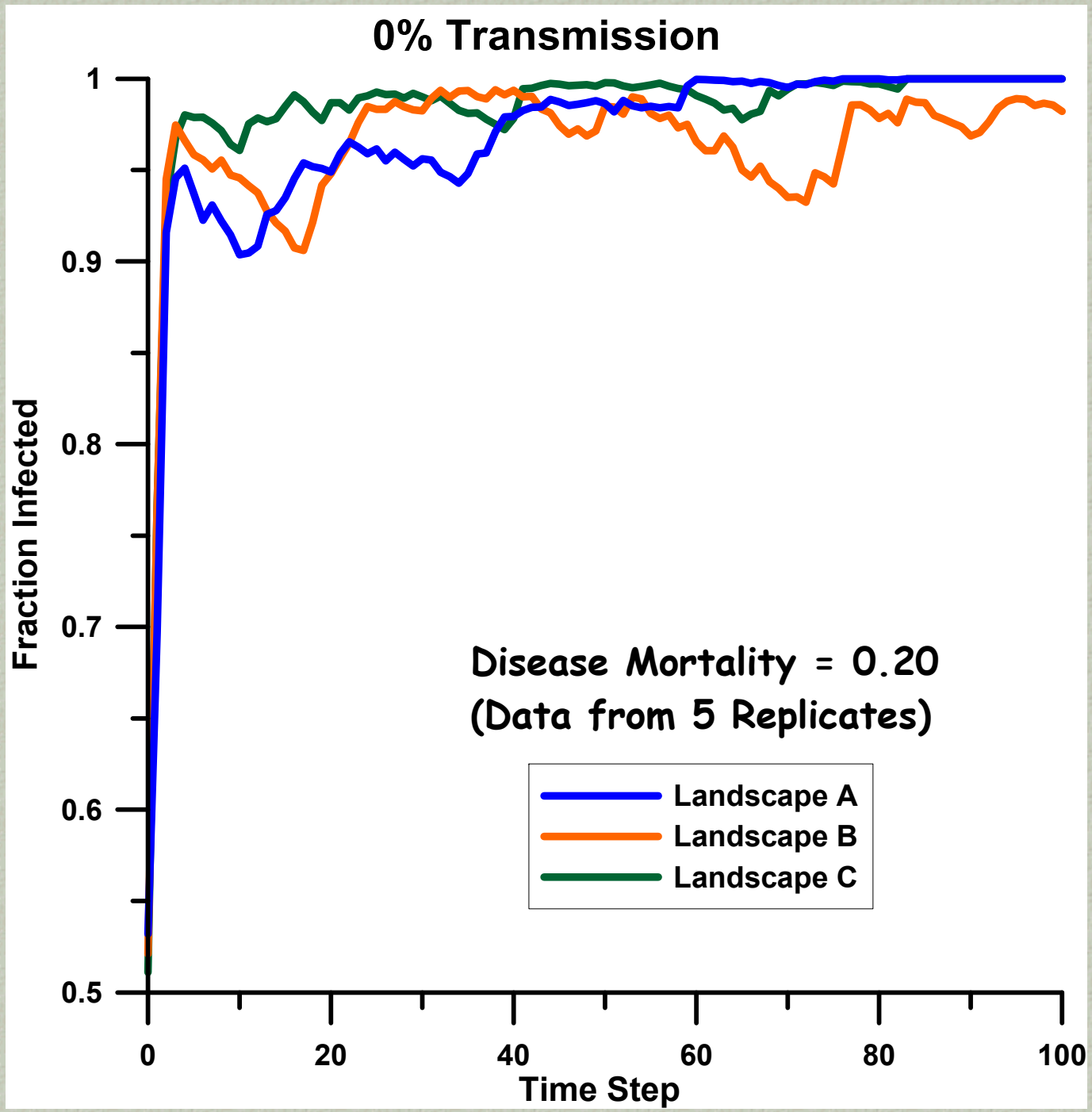

Landscape A
160
120
80
40
0
Mean Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
100% Transmission
50% Transmission
0% Transmission


Landscape B
160
120
80
40
0
Mean Population Size
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
100% Transmission
50% Transmission
0% Transmission


Landscape C
Disease Mortality = 0.20
(Data from 5 Replicates)
Mean Population Size
160
120
80
40
0
0
20
40
60
80
100
Time Step
100% Transmission
50% Transmission
0% Transmission


100% Transmission
Fraction Infected
1
0.8
0.6
0.4
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
Landscape A
Landscape B
Landscape C

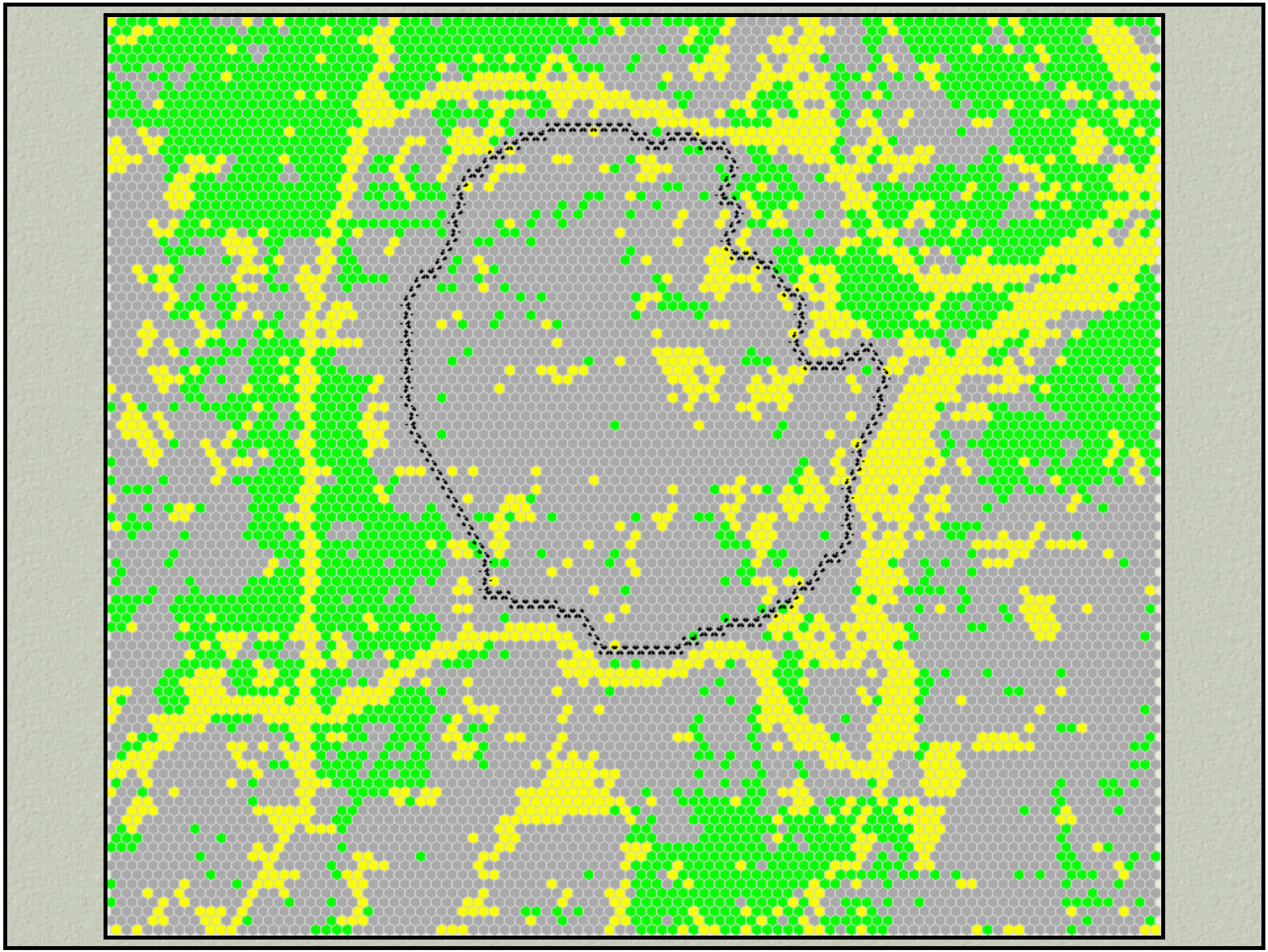

50% Transmission
Fraction Infected
1
0.8
0.6
0.4
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
Landscape A
Landscape B
Landscape C

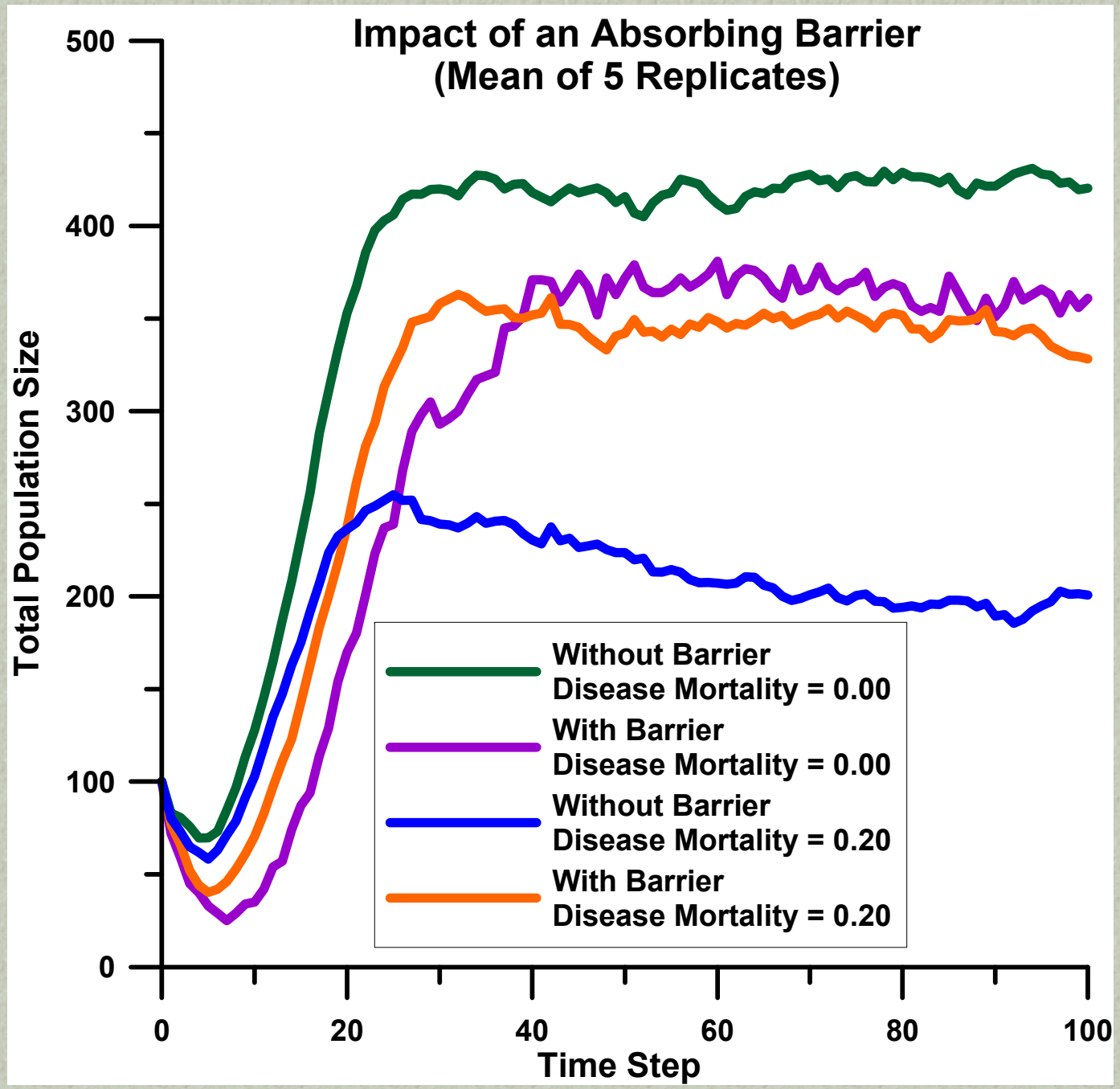

0% Transmission
Fraction Infected
1
0.9
0.8
0.7
0.6
0.5
0
20
40
60
80
100
Time Step
Disease Mortality = 0.20
(Data from 5 Replicates)
Landscape A
Landscape B
Landscape C

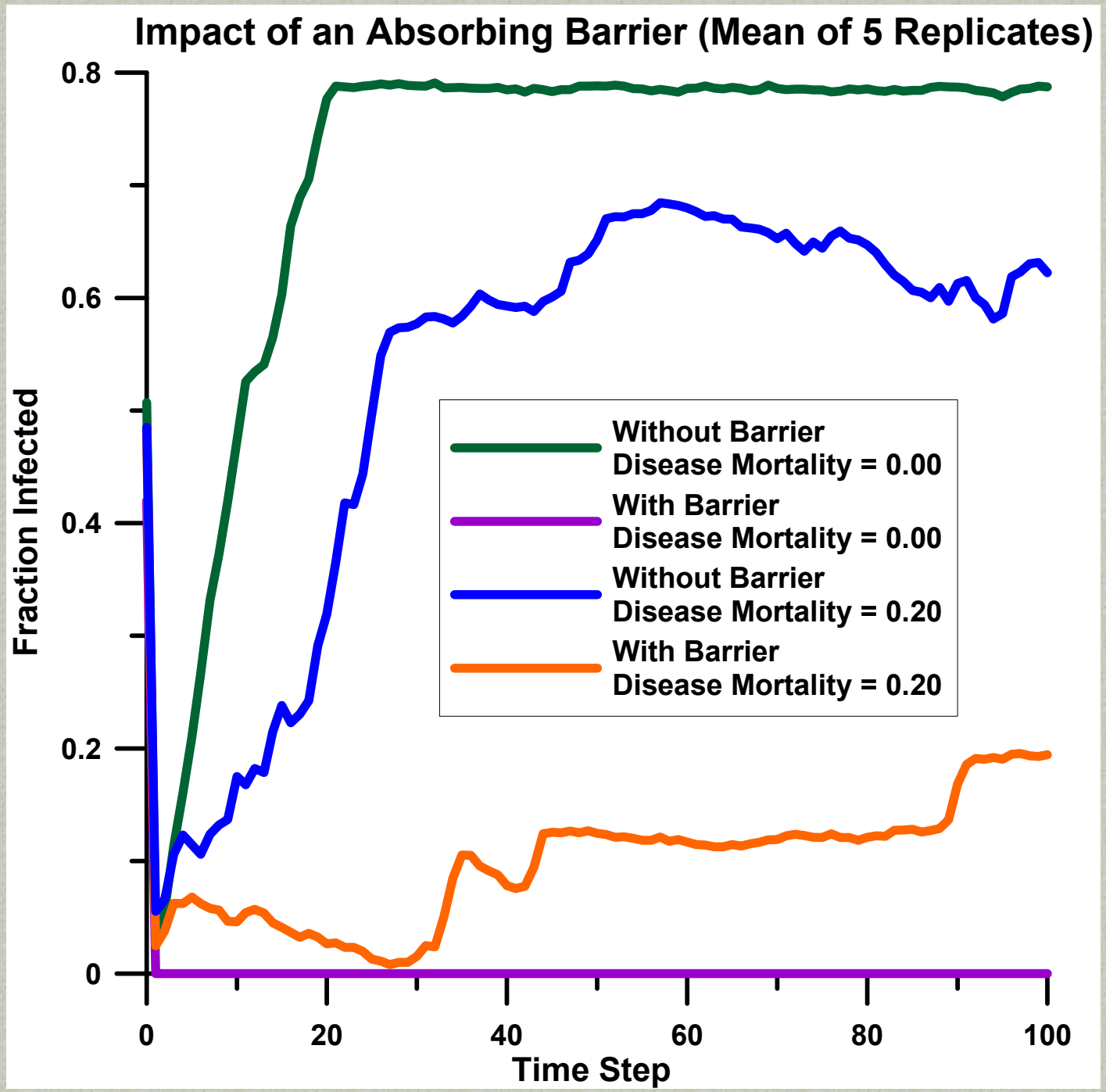
Impact Of An Absorbing Barrier

Movement from the inside out is unimpeded
Movement from the outside in causes death

For each landscape, a simulation was run with
Disease mortality = 20% only




Impact of an Absorbing Barrier
(Mean of 5 Replicates)
Total Population Size
Time Step
0
100
200
300
400
500
0
20
40
60
80
100
Without Barrier
Disease Mortality = 0.00
With Barrier
Disease Mortality = 0.00
Without Barrier
Disease Mortality = 0.20
With Barrier
Disease Mortality = 0.20


Impact of an Absorbing Barrier (Mean of 5 Replicates)
Fraction Infected
0.8
0.6
0.4
0.2
0
0
20
40
60
80
100
Time Step
Without Barrier
Disease Mortality = 0.00
With Barrier
Disease Mortality = 0.00
Without Barrier
Disease Mortality = 0.20
With Barrier
Disease Mortality = 0.20

Quick Recap

We have looked at the impact of reflecting and absorbing barriers on the disease model

- Population size did vary significantly with landscape structure (*A*, B, *C*) and connectivity
- When the disease lowered survival, the absorbing barrier had an unexpected impact